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ION AND ELECTRON DISTRIBUTIONS IN THE BOUNDARY LAYER OF HYPERSONIC VEHICLES FOR CHEMICAL NON-EQUILIBRIUM FLOW

Part I

AERODYNAMICS AND NUMERICAL RESULTS

by

Irvin Pollin

November 1971

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U.S. ARMY MATERIEL COMMAND

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Flows over non-ablating hypersonic vehicles are considered when all electrons are produced by aerodynamic heating in the boundary layer. Detailed calculations of the ion and electron distributions are presented for a vehicle with a conical nose and a semivertex angle of 10 deg, for Mach numbers 8 and 10 at sea level. Except for a small region at the nose, the boundary layer is turbulent. Diffusion of electrons with respect to the ions and neutrals is considered and ambipolar diffusion is found to occur across most of the boundary layer only at large ion-electron densities.

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1. INTRODUCTION

The accuracy with which a hypersonic vehicle receiving microwave radiation through a dielectric window can track a target is affected by electrons produced by aerodynamic heating in the boundary layer of the tracking vehicle. The plasma distorts an incoming signal by changing its propagation velocity through the plasma, refracting it at the plasma radome interface, and causing additional changes in the passage of the signal within the radome itself. Accordingly, wherever the electron number density exceeds $10^8/cm^3$, the calculation of boresight error requires a description of the electron distribution.[1]

In the present case, detailed calculations for the ion and electron distributions are given for a tracking vehicle having the form of a 10-degree semivertex cone flying at zero angle of incidence, sea level, and Mach numbers 8 and 10. We assume that the vehicle is subjected to intense aerodynamic heating for a short time duration, so that no ablation occurs and the vehicle shape is unaltered. Hence, with a pointed or slightly rounded non-ablating nose, the electron production occurs entirely within a small fraction of the hot boundary layer adjacent to the vehicle surface. For the above conditions, the boundary layer is turbulent everywhere except for a very small region near the nose.

The random·translational energy of the electrons is at most 0.4 electron-volt, and those electrons are subject to large accelerations by small electric fields. Thus, the electron production (as affected by recombination) as well as the distribution are sensitive to the small electric fields produced by charge separation, caused by the faster diffusion of electrons relative to ions from the region of higher ionization production. The electric field sets up a conduction current which tends toward ambipolar diffusion with increasing levels of ionization.

For the above flows, the enthalpy distribution is decoupled from the ionization, since the ionization enthalpy is insignificant in comparison with the local enthalpy. The ion mass fraction nowhere exceeds 10^{-4}. Accordingly, all electrons are produced through the reaction[2]

[1] Private communications, T.B.A.Senior, Univ. of Michigan, and G. Tricoles, General Dynamics-Electronics, San Diego, California, March 1971.

[2] J.Hilsenrath, and M.Klein, Tables of Thermodynamic Properties of Air in Chemical Equilibrium Including Second Virial Corrections from 1500°K to 15,000°K, Arnold Engineering Development Center, AEDC-TR-65-58, March 1965.

$$N + O \rightleftharpoons NO^+ + e \quad (1)$$

Moreover, the effect of Coulomb forces on collisions between neutral particles and between ions and neutral particles is negligible. Consequently, the neutral gas viscosity and ion diffusion coefficients are not affected by the electric field.[3]

In the present calculations, we account for the turbulent boundary layer by assuming a power-law velocity distribution for the neutral gas and an associated iso-energetic enthalpy boundary layer. This procedure allows for the complete determination of the neutral gas flow. Binary and turbulent eddy diffusion coefficients are included in the calculation of the ion-electron drift velocities. The boundary layer equations governing the electron and ion distributions are then solved exactly for dissociation equilibrium and ionization non-equilibrium.

The uncertainties in the boundary conditions, such as body temperature and body electric potential, justify use of this approximate method of solution. These conditions are usually known only to within a range of values that can yield variations in ion and electron distributions easily exceeding the error introduced by our method of solution. In addition, the effect on the ion and electron distributions by the neutral particle velocity distribution and boundary layer thickness can be readily obtained by our procedure. For prescribed boundary conditions, the present procedure permits a readily obtainable approximate evaluation of the plasma distribution for a wide range of body geometries and flow conditions.

2. NEUTRAL GAS FLOW AND THERMODYNAMIC PROPERTIES

For the cone of semivertex angle 10 deg considered here, significant shock wave ionization does not occur. High temperature and associated ionization, say $10^8/cm^3$ or larger, occur only within a small fraction of the boundary layer. As previously stated, all ions and electrons are produced by the reaction given by equation (1). Assuming ion formation from N_2 and O_2, approximately 10 ev per ion are required. The energy required to form

[3] I.Pollin, The Stagnation-Point Langmuir Probe in a Shock Tube-Theory and Measurements, Harry Diamond Labs, HDL TR-1103, 28 June 1963.

$10^{14}/cm^3$ electrons, which exceeds the equilibrium ion density formed on the above body at Mach number 10 and sea level, is 1.6 (10^{-4}) joule/cm^3. This energy is insignificant in comparison with the Mach number 10 sea level free stream total enthalpy of 7.5 joule/cm^3. Thus, the neutral gas enthalpy is decoupled from the ionization.

We assume the boundary layer neutral gas velocity profile corresponding to turbulent flow to be of the form[4-8]

$$u = u_\delta \eta^{\frac{1}{m}} \tag{2}$$

The extent of the laminar sublayer adjacent to the vehicle surface is about 1 percent of the total boundary layer thickness. Except for this displacement, the turbulent layer is unaffected by its presence, since only a small fraction of the momentum lies in the sublayer.[9,10] The velocity power law given by equation (2) is representative of a large class of fully developed turbulent boundary

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[4] R.K.Lobb, E.M.Winkler, and J.Persh, Experimental Investigation of Turbulent Boundary Layers in Hypersonic Flow, J.Aeronaut.Sci.22, 1-9-50 (1955).

[5] D.M.Bushnell, and I.F.Beckwith, Calculation of Hypersonic Turbulent Boundary Layers and Comparison With Experimental Data, AIAA Paper No. 69-684, June 16-18, 1969.

[6] H.L.Dryden, Transition from Laminar to Turbulent Flow, High Speed Aerodynamics and Jet Propulsion, Vol.V: Turbulent Flows and Heat Transfer, Princeton Univ. Press, 1959, Edited by C.C.Lin.

[7] C.M.Jackson, and R.S.Smith, A Method for Determining the Total Drag of a Pointed Body of Revolution in Supersonic Flow with Turbulent Boundary Layer, National Aeronautics and Space, NASA TN D-5046, March 1969.

[8] D.L.Brott, W.J.Yanta, R.L.Voisinet, and R.L.Lee. An Experimental Investigation of the Compressible Turbulent Boundary Layer with a Favorable Pressure Gradient, AIAA Paper No. 69-685, June 16-18,1969.

[9] Ibid.

[10] W.D.Hayes and R.F.Probstein, Hypersonic Flow Theory, pp 327-339, Academic Press, Inc., 1959.

layer flows at high and low Mach number, and therefore provides an adequate basis for determining the neutral gas velocity. The appropriate value of m appears to be between 6 and 8; m = 8 was used in the present calculations[9-12]. As previously stated, the effect on the electron distribution caused by variation of m within this range is small in comparison with that produced by other uncertainties, such as the value of the vehicle temperature.

The boundary layer thickness $\delta = \delta(x)$ (defined as the distance measured normal to the wall where the velocity is 0.99 of the local free stream value) depends on such factors as the wall temperature, vehicle contour and flight conditions.[10-12] For example, at high Mach numbers, the effect of insulating the body is an increase in the boundary layer temperature and thereby, a reduction in the density and an increase of the boundary layer thickness. Usually, δ increases as the flow proceeds downstream, and thereby new fluid continually enters the boundary layer and is heated.

For fully developed turbulent boundary layer flow, at Mach numbers 1.8 and 4.25 the boundary layer thickness on an axisymmetric cone with the semivertex angle of 12-1/2 deg was everywhere found to be less than 10 percent of the local cone radius at all angles of incidence up to at least 15 deg. At the latter angle, the value of δ on the leeward side was found to be a factor of 5 larger than that on the windward side at the same downstream station.[13] The large variation of boundary layer thickness is brought about primarily by the circumferential pressure gradient. A favorable pressure gradient (pressure decreasing in the direction of the flow) always tends to reduce the rate of increase in δ; the opposite is also true. Thus, at a given axial station, the boundary layer thickness can circumferentially vary by a factor of 2 at 2 deg angle of incidence and by a factor more than 3 at 5 deg.[13] Consequently, unless the flow conditions and body geometry are known, only approximate values of $\delta = \delta(x)$ can be prescribed.

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[11] R.K.Lobb, E.M.Winkler, and J.Persh, Experimental Investigation of Turbulent Boundary Layers in Hypersonic Flow, J.Aeronau.Sci. 22, 1-9-50,1955.

[12] D.M.Bushnell, and I.F.Beckwith, Calculation of Hypersonic Turbulent Boundary Layers and Comparison with Experimental Data, AIAA Paper No. 69-684, June 16-18, 1969.

[13] W.J.Rainbird, Turbulent Boundary Layer Growth and Separation on a Yawed 12 1/2° Cone at Mach Numbers 1.8 and 4.25. AIAA Paper No. 68-98, Jan 22-24, 1968.

The peak boundary layer electron density is reduced by diffusion, moreover, the ionization process is comparatively slow, so that equilibrium values of peak electron density are nowhere attained. Therefore, in an isoenergetic boundary layer, this means that the peak electron density will tend to increase with increasing δ. For moderate angles of incidence a reasonable estimate of δ is given by flat plate theory and Rainbird's data,[13] from which we deduce

$$\delta = bx^a \tag{3}$$

with a = 0.8. The effect of δ on the electron distribution can be calculated by adjusting b over the range $0.02 \geq b \geq 0.002$. The smaller value of δ is associated with low altitudes, the windward side of the vehicle, etc. In the calculations, b = 0.02 was used.

Th pressure distribution across the boundary layer is given by $\partial p/\partial y = 0$. For cones, in the inviscid region p = constant along a conical generator. Hence, p = constant throughout the boundary layer for conical vehicles. Inside the boundary layer,

$$\rho = p/RTZ \tag{4}$$

For a fully developed turbulent flow in dissociative equilibrium on a conical body, the boundary layer enthalpy distribution is given by the Crocco relation

$$H = h_b + (H_\delta - h_b) \frac{u}{u_\delta} ,$$

when the laminar and turbulent Prandtl and Lewis numbers are unity.[14,15] For $H_\delta = h_b$, we obtain an isoenergetic boundary layer, so that

$$h = h_b - \frac{u^2}{2} \tag{5}$$

Throughout the boundary layer, v << u; consequently, the v term is not included in the calculation for h.

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[14] W.D.Hayes and R.F.Probstein, Hypersonic Flow Theory, pp 327-339, Academic Press Inc., 1959.

[15] L.H.Back and R.F.Cuffel, Relationship Between Temperature and Velocity Profiles In A Turbulent Boundary Layer Along A Supersonic Nozzle With Heat Transfer. AIAA Journal, Nov., 1970.

Actually, the equilibrium value of h_b is limited by the recovery factor, which has the value 0.90 for turbulent boundary layers. The value of h given by (5) is everywhere at most 10 percent larger than that obtained by assuming $h_b = .90\ H_\delta$ in the Crocco relation. The resulting difference in electron distribution is well within the difference corresponding to the uncertainty in describing actual flight conditions. The effect of assuming an isoenergetic boundary layer is equivalent to attaining a given peak electron density at a slightly lower Mach number with a slightly different electron distribution.

With the use of equation (2), the energy equation becomes

$$\int_\delta^{\eta} dh = \frac{u_\delta^2}{2}\left(1-\eta^{\frac{2}{m}}\right) \tag{6}$$

In equation (6), the recovery enthalpy is reached at $\eta = (0.1)^{\frac{m}{2}}$ The enthalpy then was assumed constant for $(0.1)^{\frac{m}{2}} \geq \eta \geq 0$.

The flow thermodynamic properties at $y = \delta$ were calculated for the conical flow at zero angle of incidence with the help of the Sims' tables.[16] The formation of equilibrium values of dissociated N and O takes place within several hundred collisions.[17,18,19] The largest mean free path in the present calculations is of the order 10^{-5} cm. Thus, the boundary layer will be in chemical equilibrium with respect to the dissociated N and O. Since $T = T(\eta)$ and p = constant, the N and O distributions are functions of η only.

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[16] J.L.Sims, Tables for Supersonic Flow Around Right Circular Cones at Zero Angle of Attack, National Aeronautics and Space Administration, NASA SP-3004,1964.

[17] M.H.Bloom and M.H.Steiger, Inviscid Flow with Non-equilibrium Molecular Dissociation for Pressure Distributions Encountered in Hypersonic Flight, Journal of the Aero/Space Sciences, Vol.27, No.11, November 1960.

[18] K.L.Wray, Chemical Kinetics of High Temperature Air International Hypersonics Conference, M.I.T., Cambridge, Mass., Aug. 16-18,1961.

[19] S.C.Lin, and J.D.Teare, Rate of Ionization Behind Shock Waves in Air, II. Theoretical Interpretation, Avco Research Report 115, Sept.1962.

Moreover, because the ionization enthalpy is small in comparison with the free stream enthalpy, we may assume dissociative equilibrium in the boundary layer, and thereby $h = h(\rho, T)$. Then, with the use of equations (4) and (6), the thermodynamic properties were found for $y < \delta$ using the tables of Hilsenrath and Klein.[20] In every case, T_δ is so small that dissociation is zero and $Z = 1$ at $y = \delta$. Within the boundary layer, $Z = Z(\rho, T)$.

The component of the neutral gas velocity normal to the conical surface, v, is obtained from the mass conservation equation for axisymmetrical flow,

$$(\rho u r)_x + (\rho v r)_y = 0 \tag{7}$$

Since ρ and u are known functions of η, and r and δ are known functions of x, the solution of equation (7) becomes

$$v = \frac{a u_\delta \delta \eta^{\frac{m+1}{m}}}{x} - \left[1+a\right] \frac{\delta u_\delta P}{x} \int_0^\eta \frac{\rho\, \eta^{\frac{1}{m}}\, d\eta}{P} \tag{8}$$

Since $r \ll x$ and $\delta \ll x$, by equations (2) and (8), $v \ll u$; therefore, as previously noted, the effect of v on h is everywhere negligible. However, v has significance in the computation of the ion and electron velocities and thereby on their corresponding density distributions.

3. GOVERNING EQUATIONS FOR THE CHARGED PARTICLES

For axisymmetric flow, the conservation equations for the ions and electrons are

$$\rho u \overset{+}{s}_x + \rho v \overset{+}{s}_y = (\rho \overset{+}{D} \overset{+}{s}_y + \rho D_T \overset{+}{s}_y)_y + (\rho \overset{+}{K} \overset{+}{s} \phi_y)_y + \frac{\overset{+}{W}}{\overset{+}{c}_e} \tag{9}$$

$$\rho u \bar{s}_x + \rho v \bar{s}_y = (\rho \bar{D} \bar{s}_y + \rho D_T \bar{s}_y)_y - (\rho \bar{K} \bar{s} \phi_y)_y + \frac{\bar{W}}{\bar{c}_e} \tag{10}$$

where $\overset{+}{c}_e = \bar{c}_e = c_e$ and

$$\frac{\overset{+}{W}}{\overset{+}{M}} = \frac{\bar{W}}{\bar{M}} = \frac{d\overset{+}{\bar{n}}}{dt} = K_f \langle N \rangle \langle O \rangle - K_r \overset{+}{n} \bar{n}, \tag{11}$$

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[20] J. Hilsenrath and M. Klein, Tables of Thermodynamic Properties of Air in Chemical Equilibrium Including Second Virial Corrections from 1500° K to 15,000° K, Arnold Engineering Development Center, AEDC-TR-65-58, March 1965.

and the formation and recombination rate constants are given as[21,22,23,24]

$$K_f = 5(10^{-11})T^{-0.5} \exp(-32,500/T) \text{ and}$$

$$K_r = 3(10^{-3})T^{-1.5} \text{ cm}^3\text{/ion-sec,} \tag{12}$$

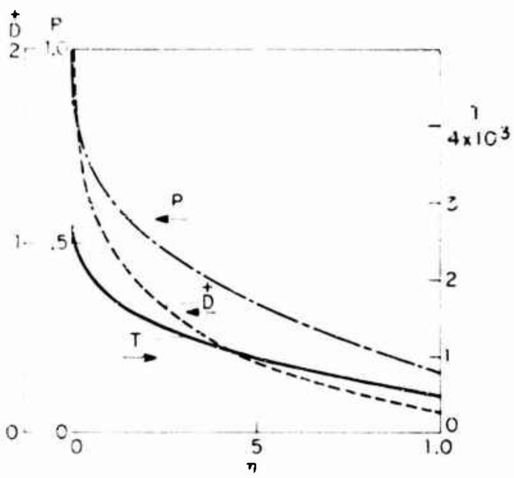

Fig. 1(a) Boundary layer parameters $\overset{+}{D}$, P and T - mach number 8

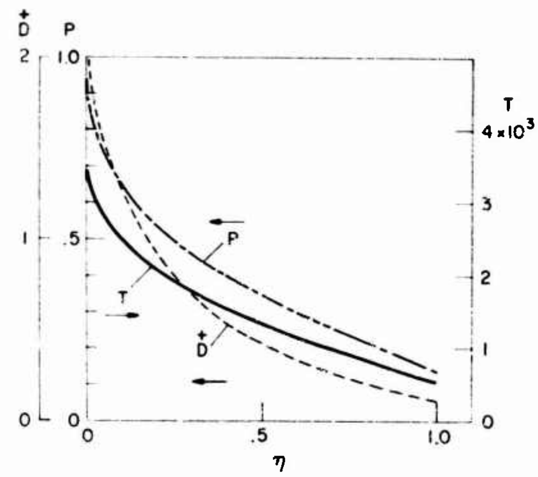

Fig. 1(b) Boundary layer parameters $\overset{+}{D}$, P and T - mach number 10

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[21] S.C.Lin, and J.D.Teare, Rate of Ionization Behind Shock Waves in Air, II, Theoretical Interpretation, Avco Research Report 115, Sept.1962.

[22] M.A.Biondi, Recombination Processes (Charged Particles), Defense Atomic Support Agency Reaction Rate Handbook, DASA 1948, Oct.1967, pp. 11-8 to 11-10.

[23] A.Q.Eschenroeder, and T.Chen, Near-Wake Ionization Behind A Sphere in Hypersonic Flight. I.Reaction Kinetics, General Motors Defense Research Labs.TR 65-01 H. Sept.,1965.

[24] A.Q.Eschenroeder, and T.Chen, Near-Wake Ionization Behind A Sphere in Hypersonic Flight. II. Influence of Flight Conditions, General Motors Defense Research Labs., TR 65-01 Q. Dec.1965.

The diffusion coefficient of NO^+ in air, denoted by $\overset{+}{D}$, is about the same as that for NO in air[25]. Consequently, using the Leonard-Jones potential, for constant pressure $\overset{+}{D}$ is a function of temperature only. Since $T = T(\eta)$, using the values given in Table V of reference 26, the dependence of $\overset{+}{D}$ on η is shown in figure 1 for sea level flight at Mach numbers 8 and 10, where the boundary layer pressures for the two cases are 4.29 and 6.00 atmospheres, respectively.

The binary diffusion coefficient for the electrons in air can be found from the approximate relation

$$\bar{D} = (\overset{+}{M}/\bar{M})^{\frac{1}{2}} (\bar{T}/\overset{+}{T})\, \overset{+}{D} = 234\overset{+}{D}, \tag{13}$$

where we have assumed $\bar{T} = \overset{+}{T}$.

When the turbulent Prandtl and Lewis numbers are unity, the turbulent eddy kinematic viscosity and turbulent eddy diffusion coefficients become equal[27]. The mixing length theory of Prandtl[28], gives $\ell = Xy$ and $\overline{u'v'} = -\ell^2 \left(\frac{d\bar{u}}{dy}\right)^2$, so that $D_T = \ell^2 \frac{d\bar{u}}{dy}$. With $X = 0.4$ and (2), there results for both ions and electrons,

$$D_T = 0.02\, u_\delta \delta \eta^{9/8}. \tag{14}$$

Since $u_\delta \approx 3(10^5)$ cm/sec, for $x > 1$cm,

$D_T > 120\eta^{9/8}$ cm²/sec. By fig. 1, except in the neighborhood of $\eta = 0$ (that is, except in the laminar sublayer), $D_T \gg \overset{+}{D}$. Similarly, $D_T \gg \bar{D}$ at somewhat larger X.

For small values of the ratio of the electric field to the total gas pressure, the Einstein equation $K = eD/kT$ or

$$K = 11{,}600\ D/T \tag{15}$$

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[25] I.Amdur and E.A.Mason, Properties of Gases at Very High Temperatures, Physics of Fluids, Vol.1, No.5, pp. 370-83, Sept-Oct 1958.

[26] I.Pollin, The Stagnation-Point Langmuir Probe in a Shock Tube--Theory and Measurements, Harry Diamond Labs, HDL TR-1103, 28 June 1963.

[27] W.D.Hayes, and R.F.Probstein, Hypersonic Flow Theory, pp 327-339, Academic Press Inc., 1959.

[28] H.Schlichting, Boundary Layer Theory, McGraw-Hill Book Co, 4th Ed., 1960, pp 477-490.

relates the mobility and binary diffusion coefficients for both electrons and ions, ref.[29]

The y component of the ion or electron current density is defined by the equation

$$J = \pm v_D e n, \tag{16}$$

($J>0$ is in the direction toward the body surface) where the y component of the average drift velocity is

$$v_D = -v + \overset{\pm}{D} s_y/s + D_T s_y/s \pm \overset{\pm}{K}\phi_y \tag{17}$$

and where (+) is for ions and (-) is for electrons. Substitution of equations (16) and (17) into equations (9) and (10) and $\eta = y/\delta$ gives

$$J_\eta = \frac{\delta e n_e u s_x}{P} - \frac{W e \delta n_e}{\rho_e c_e} - e n_e s \left(\frac{v}{P}\right)_\eta \tag{18}$$

for either ions or electrons.

Eliminating v_D in equations (16) and (17) gives

$$\overset{\pm}{s}_\eta = \frac{1}{D_T + \overset{\pm}{D}} \left[\frac{\overset{\pm}{J} P\delta}{e n_e} + \overset{\pm}{s} v\delta \mp \overset{\pm}{K}\, \overset{\pm}{s}\phi_\eta\right] \tag{19}$$

where the (-) and (+) signs preceding the electric mobility term are for ions and electrons, respectively.

Assuming $\phi_{\eta\eta} >> \delta^2 \phi_{xx}$, Poisson's equation for the electric field is

$$\phi_{\eta\eta} = -\frac{10^{14}}{8.85}\,\frac{e n_e \delta^2}{P}\,(\overset{+}{s} - \overset{-}{s}) \tag{20}$$

Previously, u, T and P were made functions of η. As we have seen, equilibrium dissociation may be assumed and thereby the <N> and <O> are only functions of η. Since the pressure is constant throughout the boundary layer, $\overset{\pm}{D}$ and $\overset{\pm}{K}$ are also functions of η only. By (14), at a given x, $D_T = D_T(\eta)$. The five equations (18)-(20) are explicit expressions for the derivatives $\overset{\pm}{J}_\eta, \overset{\pm}{s}_\eta, (\phi_\eta)_\eta$ in terms of $\overset{\pm}{J}, \overset{\pm}{s}, \overset{\pm}{s}_x, \phi_\eta$. Consequently, the computation

[29] A. Von Engle, Ionized Gases, Oxford Univ. Press,1955.

for $\overset{\pm}{J}$, $\overset{\pm}{s}$ and ϕ_η varies with η for different x through $v=v(x,\eta)$, $\xi=\xi(x)$ and $\overset{\pm}{s}_x=\overset{\pm}{s}_x(x,\eta)$.

4. BOUNDARY CONDITIONS

The solution of equations (18),(19) and (20) requires specification of five boundary conditions in addition to initial conditions at x = 0. For sharp nose cones

$$\text{at } x = 0,\ \overset{\pm}{s} = 0 \tag{21}$$

As previously stated, all ionization production occurs within a small fraction of the boundary layer adjacent to the vehicle surface. Whether a wall is catalytic or non-catalytic with respect to charged particle recombination depends on the gas-solid surface interaction, which in turn depends somewhat on the wall temperature. For the wall temperature of 1000°K assumed by Wang[30], experimental observations agree with the calculations obtained using the conditions $\overset{\pm}{s}(0) = 0$. Similarly, we assume

$$\text{at } \eta = 0,\ \overset{\pm}{s} = 0 \tag{22}$$

The temperatures at the edge of the boundary layer and for some distance therein are very low (see fig. 1). Except for the diffusion, this condition would give $\overset{\pm}{s} = 0$ at $\eta = 1$. Calculations show that nonzero boundary conditions for $\overset{\pm}{s}$ at $\eta = 1$ wherein $\overset{\pm}{s}_\eta \leq 0$ at $\eta = 1$ principally affect only the $\overset{\pm}{s}$ distributions near $\eta = 1$. Consequently, we assume

$$\text{at } \eta = 1,\ \overset{\pm}{s} = 0 \tag{23}$$

The boundary condition for an insulated surface is $J_{Net} = \overset{+}{J} + \overset{-}{J} = 0$, so that $\phi_\eta(1)$ is a function of x. Including the passage of current into the wake, $\phi_\eta(1)$ is not known for a conducting surface. The value of $(\phi_\eta)_\eta$ near $\eta = 1$ is necessarily small because of the small values of $\overset{\pm}{s}$ near $\eta = 1$ and the electric field would appear to be small at $\eta = 1$. Accordingly, for all x, we assume

$$\text{at } \eta = 1,\ \phi_\eta = 0 \tag{24}$$

Thus, (24) is an approximate boundary condition for both insulated and conducting surfaces.

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[30] K. Wang, Electron and Ion Distributions in Chemical Nonequilibrium Boundary-Layer Flows, AIAA Journal, p.316, April 1969.

In the next section, the Mach number 8 calculations show that ϕ_η is not significant in the determination of $\overset{\pm}{s}$ and $\overset{\pm}{J}$, since the $\overset{\pm}{K}\phi_y$ terms are small compared to the other diffusion terms. For Mach 10, ϕ_η is small for small x, and again the effect of ϕ_η on the calculations is negligible. At larger x, the faster electron diffusion results in significant values of ϕ_η at $\eta = 0$, fig. 3(c). Upon using these values of ϕ_η for the boundary condition (24), the effect on the $\overset{\pm}{s}$ and $\overset{\pm}{J}$ distributions (not shown) was found to be limited to the neighborhood of $\eta = 1$ and did not affect the ϕ_η at $\eta = 0$ and the peak $\overset{\pm}{n}$.

Finally, in the evaluation of ϕ, we assume

$$\text{at } \eta = 1, \ \phi = 0 \tag{25}$$

5. NUMERICAL CALCULATIONS FOR THE ION AND ELECTRON FLOW IN THE BOUNDARY LAYER

The $\overset{\pm}{s}_x(x,\eta)$ in (18) can be approximated by an appropriate finite difference expression involving $\overset{\pm}{s}(x,\eta)$, $\overset{\pm}{s}(x-\Delta x,\eta)$, etc., so that the system (18)-(20) with the boundary conditions (21)-(25) ultimately reduces to solving a two-point, nonlinear boundary-value problem at each x. This was solved numerically both by integrating the differential equations and by matrix methods.[31] As determined by reducing the step-size of the calculation intervals Δx and $\Delta\eta$ at any station x, the accuracy of any quantity was found to be within about 5 percent providing the quantity was not reduced to less than 1 percent of its maximum value. Improvement of the calculation precision requires longer computer running time.[31]

The numerical data is summarized in tables I and II and figures 2 and 3. In particular, the tables give the printout of the independent variables at typical stations $0<x\leq 100$ as well as the contributing terms to v_D. The graphs of $\overset{\pm}{n}$ were obtained from the relation

$$\overset{\pm}{n} = n_e \overset{\pm}{s}/P \tag{26}$$

where $n_e = 6.54\ (10^{10})$ and $5.63\ (10^{12})$ for Mach numbers 8 and 10 and the corresponding $P = P(\eta)$ functions are given in figure 1.

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[31] A. Hausner, Ion and Electron Distributions in the Boundary Layer of Hypersonic Vehicles For Chemical Non-Equilibrium Flow - Part II: Method of Solution and Computer Program, Harry Diamond Labs., HDL-TR 1567 1971.

All functions $\overset{\pm}{s}$, $\overset{\pm}{j}$, and ϕ_η are zero at $x = 0$. The enthalpy and density profiles of the neutral gas flow result in the total ionization production occurring within a small fraction of the boundary layer in the neighborhood of the vehicle wall. For all x, the diffusion caused by concentration gradient is directed from $\eta = 0$ toward $\eta = 1$. Thus, in the neighborhood $\eta = 0$, ion-electron recombination is negligible and the ionization production remains constant for all x. The diffusion effects become significant with increasing $\bar{s}$ and therefore with increasing x. Hence, because of the diffusion, $\frac{\partial^2 \overset{\pm}{s}}{\partial x^2} < 0$ and $\overset{+}{n} \approx n_e$ in the $\eta = 0$ neighborhood.

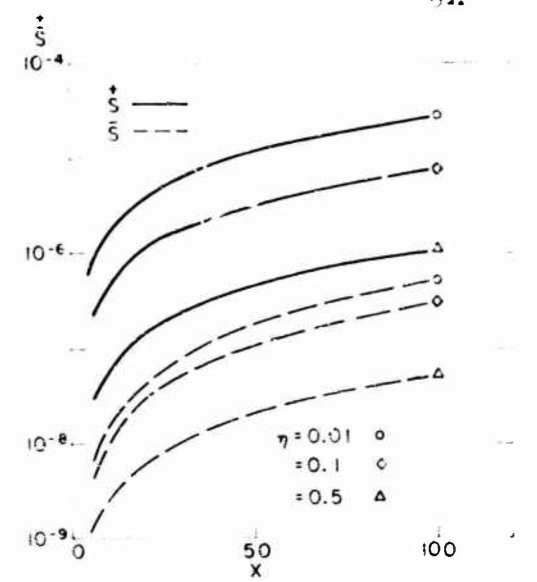

Fig. 2(a) Ion and electron densities at η = 0.01, 0.1 and 0.5 mach number 8

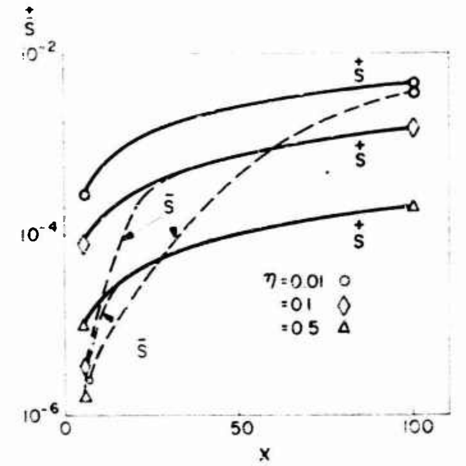

Fig. 2(b) Ion and electron densities at η = 0.01, 0.1 and 0.5 mach number 10

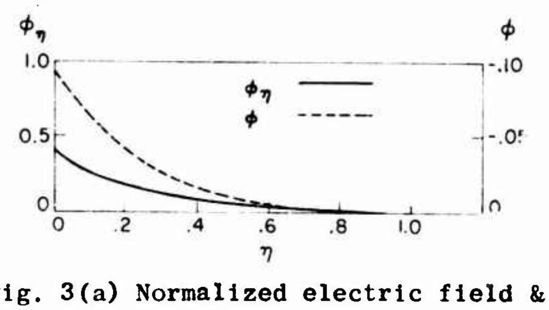

Fig. 3(a) Normalized electric field & potential at X= 100cm - mach number 8

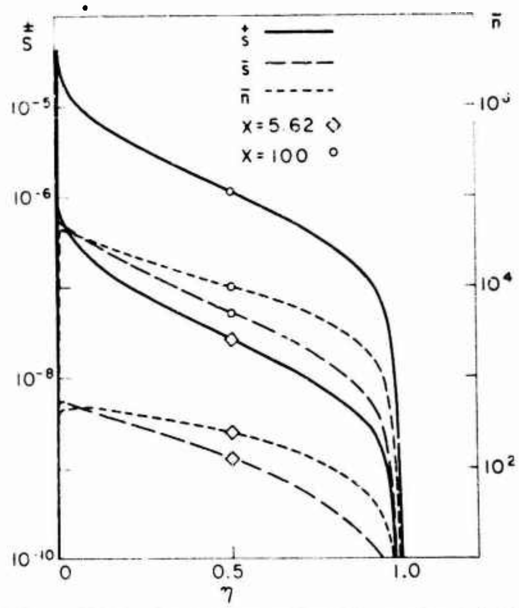

Fig. 3(b) Ion and electron densities at X = 5.62 and 100cm - mach number 8

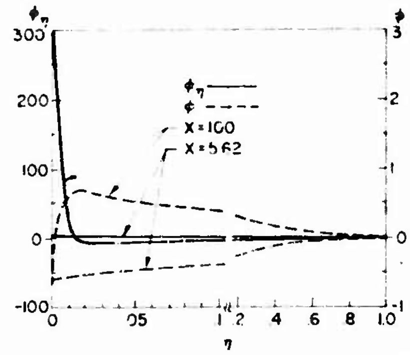

Fig. 3(c) Normalized electric field & potential at X=5.62 and 100cm mach number 10

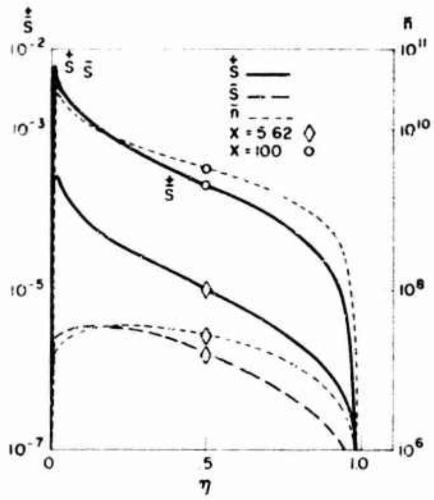

Fig. 3(d) Ion and electron densities at X = 5.62 and 100cm mach - mach number 10

From previous work[3], the u velocity is sufficiently small at $\eta \leq 10^{-4}$ to allow time for ionization equilibrium well before x = 100, particularly for Mach number 10. Ionization equilibrium at $\eta \leq 10^{-4}$ is denoted by $\overset{+}{s} = 1$. By figures 3(b) and 3(d), for Mach numbers 8 and 10, the diffusion reduces the peak electron density at x = 100 by a factor of more than 10^{1} and 10^{2}, respectively. On the other hand, for x = 100, the $\overset{+}{s}$ at $\eta > .1$ are much larger than those corresponding to ionization equilibrium. This occurrence is explained by the diffusion from the region $\eta < 0.1$ and the low recombination rate.

For the Mach number 10 calculations we observe the following behavior: Because of the faster electron diffusion over that of the ions, for small x, $\bar{s}(\eta) \ll \overset{+}{s}(\eta)$, fig. 2(b). As x increases, $\bar{s} \approx \overset{+}{s}$ near $\eta = 1$ and the η-region of approximate ion-electron equality progresses from $\eta = 1$ toward $\eta = 0$. Finally, at x = 100, $\bar{s} \approx \overset{+}{s}$ everywhere except for $\eta < 0.01$ (figs. 2(b) and 3(d)). This difference between $\bar{s}$ and $\overset{+}{s}$ gives rise to a $\phi_\eta > 0$ which increases sharply near $\eta = 0$ and is a monotonically increasing function of x at $\eta = 0$ (fig. 3(c)). The values for ϕ are obtained by integration of ϕ_η (fig. 3(c)).

[3] I. Pollin, Plasma Formation in the Boundary Layer of a Sharply Pointed Hypersonic Vehicle, Harry Diamond Labs., HDL-TR-1453, June 1969.

Referring to the $\overset{\pm}{s}$ development with x for various η in fig. 2(b), for sufficiently large x, steady state values of $\overset{\pm}{s}$ will finally evolve for the Mach number 10 case with the following characteristics:

Ambipolar diffusion occurs everywhere except in the immediate neighborhood of $\eta = 0$ where $\bar{s} < \overset{+}{s}$. Because of the large $\overset{\pm}{s}$, the $(\overset{+}{s} - \bar{s})$ difference will give rise to a large $\phi_\eta > 0$ at $\eta = 0$. The peak ion-electron densities occurring in the region $\eta \leq 10^{-4}$ will be about two orders of magnitude below ionization equilibrium, whereas the ionization for $\eta > 0.1$ will greatly exceed equilibrium conditions.

The diffusion coefficients for Mach number 8 are slightly smaller than for Mach number 10. For Mach number 8, the diffusion is more effective in reducing the peak $\overset{\pm}{n}$ because of the slower rate of ionization production. Now, the $\overset{\pm}{n}$ are everywhere markedly reduced so that the contribution to v_D by the electric field resulting from charge separation is everywhere negligible, (fig.3 (a) and table I). Hence, for Mach number 8, the electron diffusion everywhere exceeds that corresponding to ambipolar diffusion and, for all x, $\overset{+}{n} > 10\,\bar{n}$ (fig.2(a)). (If the electric field arising from the charge separation was not negligible, a counter flow diffusion would occur which would increase the peak $\bar{n}$ and reduce the peak $\overset{+}{n}$). These effects, together with the lower n_e (by two orders of magnitude) result in reduced peak $\bar{n}$ of about 5 to 6 orders of magnitude lower than those for Mach number 10.

6. CONCLUSIONS

The ion-electron distribution in the turbulent boundary layer has been calculated for a hypersonic vehicle consisting of a 10 degree semivertex, sharply pointed cone at Mach numbers 8 and 10 for sea level flight. Binary and turbulent eddy diffusions across the boundary layer normal to the vehicle surface act to reduce the peak $\overset{\pm}{n}$ whereas the electric field arising from the charge separation acts to cause ambipolar diffusion and thereby acts to increase the peak $\bar{n}$ and decrease the peak $\overset{+}{n}$. For the cases considered, a balance between the ionization production and diffusion results in the attainment of a steady state peak electron density of about two orders of magnitude less than equilibrium ionization at Mach number 10 and a reduction of about six orders at Mach number 8. Moreover, the distance along the missile surface required to attain the steady state peak electron density in the present calculation is several times larger

than the corresponding distance to attain peak equilibrium ionization for the same flight wherein all diffusion is neglected.

The calculation procedure allows for an easy evaluation of the effect of the neutral gas enthalpy profile, boundary layer thickness, binary and eddy turbulent diffusion coefficients, etc., on the ion-electron turbulent boundary layer distributions.

The described procedure can be used to determine the ionization distributions in the turbulent boundary layer of sharply pointed vehicles for Mach numbers up to 15 at sea level and 20 at the altitude 10^5 ft. The ion mass fraction exceeds 10^{-4} at higher Mach numbers, and the electron production is no longer adequately given by reaction (1).

The assumption of the boundary conditions $s = 0$ at $x = 0$ requires a sharply pointed nose. For slightly rounded and blunt nosed vehicles, in the nose shock region, shock induced ionization governs the ion and electron distributions; however, diffusion, initially aided by recombination, will produce rapid reductions of the $\overset{+}{n}$ as the flow proceeds downstream. Consequently, for the extension to blunt nose bodies, we can assume the initial conditions to be those corresponding to equilibrium ionization behind the nose shock and proceed therefrom as before.

7. LIST OF SYMBOLS

c_j	mass fraction of component j
D	binary diffusion coefficient, cm^2/sec
D_T	turbulent eddy diffusion coefficient, cm^2/sec
e	electron charge = $1.60\ (10^{-19})$ coulomb = $4.80(10^{-10})$ esu
h	enthalpy per unit mass of mixture
H	total enthalpy per unit mass of mixture = $h+V^2$
J	y component of ion current density, Amp/cm^2
K	electric field mobility coefficient, $cm^2/V\text{-}sec$
K_f	rate constant for ion-electron formation, $cm^3/ion\text{-}sec$
K_r	rate constant for ion-electron recombination, $cm^3/ion\text{-}sec$
m	velocity profile power law coefficient = 8
M	mass, g
n	ion or electron number density, cm^{-3}
<N>	nitrogen number density, $atom/cm^3$
<O>	oxygen number density, $atom/cm^3$
p	pressure kg/m^2 or atmosphere
P	density ratio = ρ_e/ρ
r	radial distance of vehicle surface from axis of symmetry,cm
R	gas constant for air = 1.987 cal/mole°K
s	mass fraction for ions or electrons = c/c_e
t	time, sec
T	absolute temperature, °K
u	x component of neutral gas mixture velocity, cm/sec
v	y component of neutral gas mixture velocity, cm/sec
V	speed of neutral gas mixture velocity = $\sqrt{u^2 + v^2}$, cm/sec

W mass rate of formation of ions or electrons, g/sec-cm^3

x distance along meridian profile, cm

y distance normal to the surface, cm

Z compressibility factor $= p/\rho RT$ ($Z = 1$ at STP)

δ boundary layer thickness, cm

η dimensionless boundary layer thickness $= y/\delta$

k Boltzmann constant $= 1.38 (10^{-23})$ joule/°K

ρ mass density, kg/m^3

ϕ electric potential, V

Subscripts

b vehicle surface

D y component of total ion or electron velocity, cm/sec

e recovery temperature condition ($\eta \leq 10^{-4}$)

x partial differentiation along meridian profile

y partial differentiation along surface normal

δ edge of boundary layer

η partial differentiation along dimensionless surface normal

Superscripts

$-$ electron

$+$ ion

TABLE I   MACH NUMBER 8

(1)

X = 5.62   DELTA Z = 0.3981   ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	KPLUS *PHIY	D PLUS *SY/S	D MINUS *SY/S	DTPLUS *SY/S	DTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	3.962E-10	4.112E-10	1.036E-04	-2.20E-05	0.00E-39	1.16E-02	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.35E-04	1.90E 02	5.821E-07	2.736E-09	1.114E-10	1.254E-10	1.034E-04	-2.19E-05	9.83E-01	1.12E-02	1.61E 04	4.17E 06	1.15E 03	1.27E 03
1.75E-03	2.79E 02	7.907E-07	3.935E-09	4.297E-11	5.795E-11	1.029E-04	-2.18E-05	2.27E 00	1.10E-02	4.09E 03	1.30E 06	6.98E 02	9.46E 02
2.76E-03	3.31E 02	8.692E-07	4.576E-09	1.420E-11	2.915E-11	1.022E-04	-2.17E-05	3.73E 00	1.08E-02	1.09E 03	5.49E 05	3.20E 02	6.72E 02
3.88E-03	3.65E 02	8.889E-07	4.947E-09	7.647E-13	1.566E-11	1.014E-04	-2.16E-05	5.39E 00	1.05E-02	4.66E 01	2.47E 05	2.06E 01	5.09E 02
5.10E-03	3.88E 02	8.799E-07	5.173E-09	-6.098E-12	8.742E-12	1.005E-04	-2.15E-05	7.31E 00	1.03E-02	-3.51E 02	1.41E 05	-2.24E 02	3.74E 02
6.45E-03	4.04E 02	8.559E-07	5.314E-09	-9.872E-12	4.904E-12	9.946E-05	-2.13E-05	9.45E 00	1.01E-02	-5.23E 02	7.56E 04	-4.34E 02	2.58E 02
7.94E-03	4.17E 02	8.241E-07	5.401E-09	-1.203E-11	2.673E-12	9.837E-05	-2.12E-05	1.18E 01	9.94E-03	-5.76E 02	3.99E 04	-6.18E 02	1.83E 02
9.57E-03	4.27E 02	7.882E-07	5.452E-09	-1.331E-11	1.324E-12	9.721E-05	-2.10E-05	1.45E 01	9.73E-03	-5.78E 02	1.93E 04	-7.84E 02	1.12E 02
1.14E-02	4.34E 02	7.504E-07	5.477E-09	-1.404E-11	5.086E-13	9.597E-05	-2.08E-05	1.75E 01	9.52E-03	-5.56E 02	7.25E 03	-9.36E 02	5.21E 01
1.34E-02	4.40E 02	7.120E-07	5.485E-09	-1.446E-11	-2.333E-15	9.465E-05	-2.07E-05	2.09E 01	9.31E-03	-5.24E 02	-5.14E 01	-1.08E 03	-4.52E-01
1.55E-02	4.46E 02	6.737E-07	5.478E-09	-1.467E-11	-3.072E-13	9.326E-05	-2.05E-05	2.46E 01	9.09E-03	-4.86E 02	-4.29E 03	-1.21E 03	-4.57E 01
1.79E-02	4.50E 02	6.361E-07	5.462E-09	-1.474E-11	-4.805E-13	9.180E-05	-2.02E-05	2.87E 01	8.86E-03	-4.46E 02	-6.61E 03	-1.34E 03	-8.49E 01
2.06E-02	4.55E 02	5.995E-07	5.439E-09	-1.473E-11	-5.748E-13	9.026E-05	-2.00E-05	3.32E 01	8.63E-03	-4.07E 02	-7.91E 03	-1.46E 03	-1.20E 02
2.35E-02	4.58E 02	5.641E-07	5.409E-09	-1.467E-11	-6.251E-13	8.865E-05	-1.97E-05	3.83E 01	8.40E-03	-3.72E 02	-8.41E 03	-1.58E 03	-1.55E 02
2.67E-02	4.62E 02	5.299E-07	5.374E-09	-1.457E-11	-6.509E-13	8.695E-05	-1.94E-05	4.29E 01	8.17E-03	-3.34E 02	-8.67E 03	-1.71E 03	-1.88E 02
3.02E-02	4.65E 02	4.969E-07	5.335E-09	-1.446E-11	-6.631E-13	8.518E-05	-1.91E-05	5.00E 01	7.92E-03	-3.08E 02	-8.74E 03	-1.83E 03	-2.21E 02
3.41E-02	4.68E 02	4.553E-07	5.290E-09	-1.432E-11	-6.681E-13	8.332E-05	-1.88E-05	5.68E 01	7.67E-03	-2.80E 02	-8.71E 03	-1.95E 03	-2.60E 02
3.84E-02	4.72E 02	4.349E-07	5.241E-09	-1.418E-11	-6.693E-13	8.138E-05	-1.85E-05	6.42E 01	7.40E-03	-2.53E 02	-8.65E 03	-2.07E 03	-3.02E 02
4.31E-02	4.74E 02	4.059E-07	5.186E-09	-1.403E-11	-6.686E-13	7.935E-05	-1.81E-05	7.24E 01	7.14E-03	-2.30E 02	-8.53E 03	-2.20E 03	-3.49E 02
4.82E-02	4.77E 02	3.779E-07	5.125E-09	-1.387E-11	-6.669E-13	7.723E-05	-1.77E-05	8.15E 01	6.87E-03	-2.09E 02	-8.42E 03	-2.34E 03	-4.03E 02
5.39E-02	4.79E 02	3.513E-07	5.058E-09	-1.370E-11	-6.646E-13	7.503E-05	-1.72E-05	9.14E 01	6.59E-03	-1.89E 02	-8.32E 03	-2.48E 03	-4.64E 02
6.02E-02	4.81E 02	3.258E-07	4.984E-09	-1.352E-11	-6.618E-13	7.274E-05	-1.68E-05	1.02E 02	6.31E-03	-1.72E 02	-8.17E 03	-2.62E 03	-5.34E 02
6.71E-02	4.82E 02	3.015E-07	4.903E-09	-1.333E-11	-6.585E-13	7.037E-05	-1.63E-05	1.14E 02	6.03E-03	-1.55E 02	-8.04E 03	-2.77E 03	-6.13E 02
7.47E-02	4.82E 02	2.784E-07	4.814E-09	-1.313E-11	-6.549E-13	6.790E-05	-1.58E-05	1.27E 02	5.74E-03	-1.41E 02	-7.91E 03	-2.93E 03	-7.02E 02
8.31E-02	4.82E 02	2.564E-07	4.716E-09	-1.293E-11	-6.508E-13	6.536E-05	-1.52E-05	1.42E 02	5.45E-03	-1.28E 02	-7.77E 03	-3.10E 03	-8.03E 02
9.23E-02	4.82E 02	2.355E-07	4.608E-09	-1.271E-11	-6.463E-13	6.273E-05	-1.46E-05	1.57E 02	5.16E-03	-1.16E 02	-7.63E 03	-3.27E 03	-9.19E 02
1.02E-01	4.80E 02	2.156E-07	4.491E-09	-1.248E-11	-6.414E-13	6.002E-05	-1.40E-05	1.75E 02	4.87E-03	-1.05E 02	-7.44E 03	-3.46E 03	-1.05E 03
1.14E-01	4.75E 02	1.968E-07	4.364E-09	-1.225E-11	-6.359E-13	5.723E-05	-1.33E-05	1.94E 02	4.58E-03	-9.57E 01	-7.34E 03	-3.66E 03	-1.20E 03
1.26E-01	4.72E 02	1.790E-07	4.225E-09	-1.201E-11	-6.299E-13	5.438E-05	-1.27E-05	2.14E 02	4.28E-03	-8.68E 01	-7.19E 03	-3.88E 03	-1.37E 03
1.39E-01	4.67E 02	1.622E-07	4.075E-09	-1.176E-11	-6.234E-13	5.147E-05	-1.19E-05	2.36E 02	3.97E-03	-7.96E 01	-7.02E 03	-4.12E 03	-1.57E 03
1.54E-01	4.60E 02	1.464E-07	3.912E-09	-1.150E-11	-6.163E-13	4.850E-05	-1.12E-05	2.60E 02	3.67E-03	-7.09E 01	-6.82E 03	-4.36E 03	-1.80E 03
1.71E-01	4.53E 02	1.316E-07	3.737E-09	-1.124E-11	-6.085E-13	4.547E-05	-1.04E-05	2.85E 02	3.37E-03	-6.38E 01	-6.63E 03	-4.65E 03	-2.05E 03
1.89E-01	4.44E 02	1.177E-07	3.550E-09	-1.097E-11	-6.001E-13	4.240E-05	-9.64E-06	3.12E 02	3.08E-03	-5.74E 01	-6.41E 03	-4.91E 03	-2.35E 03
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2.30E-01	4.20E 02	9.271E-08	3.142E-09	-1.041E-11	-5.815E-13	3.615E-05	-8.00E-06	3.71E 02	2.52E-03	-4.67E 01	-5.98E 03	-5.58E 03	-3.05E 03
2.55E-01	4.05E 02	8.154E-08	2.922E-09	-1.013E-11	-5.714E-13	3.300E-05	-7.17E-06	4.03E 02	2.24E-03	-4.21E 01	-5.74E 03	-5.95E 03	-3.46E 03
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3.10E-01	3.70E 02	6.174E-08	2.458E-09	-9.560E-12	-5.495E-13	2.671E-05	-5.51E-06	4.69E 02	1.72E-03	-3.39E 01	-5.23E 03	-6.87E 03	-4.52E 03
3.42E-01	3.49E 02	5.305E-08	2.218E-09	-9.278E-12	-5.381E-13	2.360E-05	-4.71E-06	5.03E 02	1.49E-03	-3.05E 01	-4.97E 03	-7.42E 03	-5.17E 03
3.78E-01	3.26E 02	4.512E-08	1.975E-09	-8.999E-12	-5.263E-13	2.054E-05	-3.93E-06	5.37E 02	1.25E-03	-2.73E 01	-4.70E 03	-8.05E 03	-5.92E 03
4.17E-01	3.01E 02	3.792E-08	1.732E-09	-8.725E-12	-5.143E-13	1.755E-05	-3.19E-06	5.72E 02	1.03E-03	-2.47E 01	-4.45E 03	-8.82E 03	-5.30E 03
4.59E-01	2.74E 02	3.139E-08	1.493E-09	-8.460E-12	-5.025E-13	1.466E-05	-2.50E-06	6.00E 02	8.34E-04	-2.24E 01	-4.21E 03	-9.7[illegible] 03	-7.45E 03
5.06E-01	2.46E 02	2.552E-08	1.259E-09	-8.211E-12	-4.910E-13	1.191E-05	-1.88E-06	6.33E 02	6.51E-04	-2.03E 01	-3.98E 03	-1.09E 04	-9.14E 03
5.58E-01	2.16E 02	2.027E-08	1.035E-09	-7.980E-12	-4.802E-13	9.309E-06	-1.33E-06	6.50E 02	4.86E-04	-1.84E 01	-3.75E 03	-1.24E 04	-1.08E 04
6.15E-01	1.85E 02	1.561E-08	8.212E-10	-7.772E-12	-4.703E-13	6.907E-06	-8.66E-07	6.55E 02	3.42E-04	-1.69E 01	-3.55E 03	-1.44E 04	-1.30E 04
6.78E-01	1.53E 02	1.151E-08	6.218E-10	-7.591E-12	-4.615E-13	4.745E-06	-5.02E-07	6.41E 02	2.22E-04	-1.57E 01	-3.41E 03	-1.74E 04	-1.61E 04
7.48E-01	1.19E 02	7.931E-09	4.385E-10	-7.442E-12	-4.543E-13	2.881E-06	-2.41E-07	6.02E 02	1.26E-04	-1.53E 01	-3.39E 03	-2.22E 04	-2.11E 04
8.24E-01	8.28E 01	4.841E-09	2.730E-10	-7.329E-12	-4.488E-13	1.390E-06	-8.19E-08	5.36E 02	5.63E-05	-1.52E 01	-3.67E 03	-3.17E 04	-3.07E 04
9.08E-01	4.37E 01	2.195E-09	1.259E-10	-7.263E-12	-4.457E-13	3.826E-07	-1.19E-08	4.02E 02	1.41E-05	-2.18E 01	-5.02E 03	-6.00E 04	-5.91E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-7.245E-12	-4.449E-13	0.000E-39	0.00E-39	1.27E 02	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38

TABLE I MACH NUMBER 8 (Contd) (2)

X = 22.20 DELTA Z = 0.3981 ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	KPLUS *PHIY	Q PLUS *SY/S	Q MINUS *SY/S	QTPLUS *SY/S	QTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	1.149E-09	1.232E-09	5.780E-03	-1.26E-03	0.00E-39	2.15E-01	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.35E-04	1.70E 03	4.691E-06	2.457E-08	2.949E-10	3.718E-10	5.763E-03	-1.25E-03	7.47E-01	2.09E-01	4.67E 03	1.39E 06	9.99E 02	1.26E 03
1.75E-03	2.50E 03	5.776E-06	3.529E-08	8.970E-11	1.725E-10	5.727E-03	-1.25E-03	1.72E 00	2.04E-01	8.74E 02	4.30E 05	4.47E 02	9.40E 02
2.76E-03	2.97E 03	6.244E-06	4.093E-08	3.505E-12	8.605E-11	5.681E-03	-1.24E-03	2.83E 00	2.00E-01	2.41E 01	1.81E 05	2.13E 01	6.82E 02
3.88E-03	3.27E 03	6.135E-06	4.424E-08	-3.671E-11	4.558E-11	5.630E-03	-1.24E-03	4.10E 00	1.95E-01	-2.19E 02	8.66E 04	-2.92E 02	4.76E 02
5.10E-03	3.45E 03	5.884E-06	4.619E-08	-5.719E-11	2.483E-11	5.574E-03	-1.23E-03	5.56E 00	1.91E-01	-2.85E 02	4.45E 04	-5.[illegible]E 02	3.55E 02
6.45E-03	3.60E 03	5.581E-06	4.736E-08	-6.840E-11	1.331E-11	5.514E-03	-1.22E-03	7.18E 00	1.87E-01	-2.91E 02	2.29E 04	-7.24E 02	2.44E 02
7.94E-03	3.71E 03	5.267E-06	4.804E-08	-7.476E-11	6.622E-12	5.451E-03	-1.21E-03	9.00E 00	1.84E-01	-2.75E 02	1.10E 04	-8.64E 02	1.52E 02
9.57E-03	3.79E 03	4.957E-06	4.839E-08	-7.846E-11	2.577E-12	5.384E-03	-1.20E-03	1.10E 01	1.80E-01	-2.51E 02	4.21E 03	-1.02E 03	7.52E 01
1.14E-02	3.85E 03	4.659E-06	4.849E-08	-8.053E-11	1.339E-13	5.315E-03	-1.19E-03	1.33E 01	1.76E-01	-2.28E 02	2.40E 02	-1.15E 03	5.18E 00
1.34E-02	3.89E 03	4.375E-06	4.843E-08	-8.167E-11	-1.396E-12	5.242E-03	-1.18E-03	1.59E 01	1.72E-01	-2.05E 02	-2.16E 03	-1.26E 03	-5.71E 01
1.55E-02	3.92E 03	4.105E-06	4.823E-08	-8.216E-11	-2.308E-12	5.166E-03	-1.17E-03	1.87E 01	1.68E-01	-1.83E 02	-3.54E 03	-1.37E 03	-1.13E 02
1.79E-02	3.95E 03	3.850E-06	4.793E-08	-8.223E-11	-2.824E-12	5.086E-03	-1.16E-03	2.18E 01	1.64E-01	-1.64E 02	-4.26E 03	-1.46E 03	-1.65E 02
2.06E-02	3.98E 03	3.609E-06	4.754E-08	-8.204E-11	-3.103E-12	5.003E-03	-1.15E-03	2.53E 01	1.59E-01	-1.46E 02	-4.65E 03	-1.53E 03	-2.14E 02
2.35E-02	3.99E 03	3.382E-06	4.709E-08	-8.168E-11	-3.250E-12	4.916E-03	-1.13E-03	2.91E 01	1.55E-01	-1.31E 02	-4.82E 03	-1.60E 03	-2.63E 02
2.67E-02	4.00E 03	3.166E-06	4.658E-08	-8.123E-11	-3.323E-12	4.825E-03	-1.12E-03	3.34E 01	1.51E-01	-1.18E 02	-4.87E 03	-1.78E 03	-3.15E 02
3.02E-02	4.01E 03	2.962E-06	4.601E-08	-8.070E-11	-3.354E-12	4.730E-03	-1.10E-03	3.80E 01	1.47E-01	-1.06E 02	-4.86E 03	-1.89E 03	-3.70E 02
3.41E-02	4.02E 03	2.769E-06	4.537E-08	-8.011E-11	-3.363E-12	4.631E-03	-1.08E-03	4.32E 01	1.42E-01	-9.52E 01	-4.81E 03	-1.99E 03	-4.30E 02
3.84E-02	4.02E 03	2.585E-06	4.467E-08	-7.948E-11	-3.360E-12	4.528E-03	-1.06E-03	4.88E 01	1.37E-01	-8.54E 01	-4.74E 03	-2.10E 03	-4.98E 02
4.31E-02	4.02E 03	2.411E-06	4.390E-08	-7.882E-11	-3.351E-12	4.420E-03	-1.04E-03	5.50E 01	1.33E-01	-7.69E 01	-4.67E 03	-2.21E 03	-5.73E 02
4.82E-02	4.00E 03	2.246E-06	4.307E-08	-7.811E-11	-3.338E-12	4.307E-03	-1.02E-03	6.19E 01	1.28E-01	-6.94E 01	-4.58E 03	-2.33E 03	-6.58E 02
5.39E-02	3.99E 03	2.088E-06	4.215E-08	-7.72[illegible]E-11	-3.322E-12	4.190E-03	-9.94E-04	6.94E 01	1.22E-01	-6.25E 01	-4.49E 03	-2.45E 03	-7.52E 02
6.02E-02	3.97E 03	1.939E-06	4.116E-08	-7.657E-11	-3.304E-12	4.069E-03	-9.68E-04	7.77E 01	1.18E-01	-5.64E 01	-4.39E 03	-2.58E 03	-8.50E 02
6.71E-02	3.94E 03	1.796E-06	4.009E-08	-7.574E-11	-3.284E-12	3.942E-03	-9.41E-04	8.68E 01	1.13E-01	-5.08E 01	-4.29E 03	-2.72E 03	-9.80E 02
7.47E-02	3.90E 03	1.661E-06	3.893E-08	-7.487E-11	-3.262E-12	3.811E-03	-9.11E-04	9.67E 01	1.07E-01	-4.59E 01	-4.16E 03	-2.86E 03	-1.11E 03
8.31E-02	3.85E 03	1.533E-06	3.769E-08	-7.396E-11	-3.238E-12	3.674E-03	-8.80E-04	1.08E 02	1.02E-01	-4.15E 01	-4.07E 03	-3.01E 03	-1.26E 03
9.23E-02	3.80E 03	1.411E-06	3.636E-08	-7.300E-11	-3.212E-12	3.534E-03	-8.47E-04	1.20E 02	9.70E-02	-3.75E 01	-3.95E 03	-3.18E 03	-1.43E 03
1.02E-01	3.73E 03	1.296E-06	3.494E-08	-7.200E-11	-3.183E-12	3.388E-03	-8.12E-04	1.33E 02	9.16E-02	-3.39E 01	-3.83E 03	-3.35E 03	-1.61E 03
1.14E-01	3.65E 03	1.186E-06	3.344E-08	-7.096E-11	-3.151E-12	3.238E-03	-7.75E-04	1.47E 02	8.63E-02	-3.08E 01	-3.71E 03	-3.54E 03	-1.82E 03
1.26E-01	3.56E 03	1.082E-06	3.185E-08	-6.988E-11	-3.118E-12	3.084E-03	-7.36E-04	1.63E 02	8.09E-02	-2.79E 01	-3.57E 03	-3.75E 03	-2.05E 03
1.39E-01	3.46E 03	9.843E-07	3.019E-08	-6.876E-11	-3.082E-12	2.927E-03	-6.95E-04	1.79E 02	7.53E-02	-2.53E 01	-3.43E 03	-3.97E 03	-2.30E 03
1.54E-01	3.35E 03	8.916E-07	2.846E-08	-6.761E-11	-3.043E-12	2.765E-03	-6.53E-04	1.97E 02	6.97E-02	-2.28E 01	-3.28E 03	-4.20E 03	-2.59E 03
1.71E-01	3.23E 03	8.044E-07	2.666E-08	-6.641E-11	-3.002E-12	2.599E-03	-6.09E-04	2.17E 02	6.42E-02	-2.05E 01	-3.11E 03	-4.40E 03	-2.90E 03
1.89E-01	3.10E 03	7.226E-07	2.482E-08	-6.518E-11	-2.959E-12	2.431E-03	-5.64E-04	2.37E 02	5.88E-02	-1.84E 01	-2.95E 03	-4.73E 03	-3.23E 03
2.09E-01	2.96E 03	6.460E-07	2.295E-08	-6.393E-11	-2.913E-12	2.259E-03	-5.17E-04	2.59E 02	5.35E-02	-1.66E 01	-2.76E 03	-5.03E 03	-3.60E 03
2.30E-01	2.81E 03	5.744E-07	2.105E-08	-6.265E-11	-2.865E-12	2.085E-03	-4.70E-04	2.82E 02	4.84E-02	-1.50E 01	-2.62E 03	-5.37E 03	-4.01E 03
2.55E-01	2.65E 03	5.076E-07	1.916E-08	-6.135E-11	-2.816E-12	1.909E-03	-4.21E-04	3.06E 02	4.33E-02	-1.35E 01	-2.46E 03	-5.74E 03	-4.46E 03
2.81E-01	2.49E 03	4.456E-07	1.728E-08	-6.004E-11	-2.765E-12	1.733E-03	-3.73E-04	3.31E 02	3.83E-02	-1.22E 01	-2.29E 03	-6.15E 03	-4.96E 03
3.10E-01	2.32E 03	3.882E-07	1.543E-08	-5.872E-11	-2.713E-12	1.556E-03	-3.25E-04	3.56E 02	3.35E-02	-1.09E 01	-2.13E 03	-6.63E 03	-5.52E 03
3.42E-01	2.15E 03	3.353E-07	1.364E-08	-5.741E-11	-2.660E-12	1.379E-03	-2.78E-04	3.82E 02	2.88E-02	-9.62E 00	-1.97E 03	-7.17E 03	-6.15E 03
3.78E-01	1.97E 03	2.866E-07	1.190E-08	-5.611E-11	-2.607E-12	1.205E-03	-2.33E-04	4.08E 02	2.44E-02	-8.83E 00	-1.82E 03	-7.80E 03	-6.87E 03
4.17E-01	1.78E 03	2.421E-07	1.024E-08	-5.482E-11	-2.554E-12	1.033E-03	-1.89E-04	4.35E 02	2.03E-02	-7.99E 00	-1.68E 03	-8.57E 03	-7.71E 03
4.59E-01	1.59E 03	2.015E-07	8.662E-09	-5.358E-11	-2.502E-12	8.657E-04	-1.49E-04	4.61E 02	1.54E-02	-7.27E 00	-1.56E 03	-9.51E 03	-8.73E 03
5.06E-01	1.40E 03	1.646E-07	7.182E-09	-5.240E-11	-2.452E-12	7.053E-04	-1.12E-04	4.81E 02	1.29E-02	-6.62E 00	-1.45E 03	-1.07E 04	-9.97E 03
5.58E-01	1.21E 03	1.314E-07	5.808E-09	-5.131E-11	-2.406E-12	5.531E-04	-7.92E-05	4.94E 02	9.63E-03	-6.03E 00	-1.34E 03	-1.22E 04	-1.15E 04
6.15E-01	1.03E 03	1.016E-07	4.545E-09	-5.032E-11	-2.364E-12	4.115E-04	-5.18E-05	4.99E 02	6.80E-03	-5.54E 00	-1.25E 03	-1.42E 04	-1.37E 04
6.78E-01	8.36E 02	7.524E-08	3.398E-09	-4.945E-11	-2.327E-12	2.935E-04	-3.01E-05	4.87E 02	4.41E-03	-5.19E 00	-1.18E 03	-1.72E 04	-1.67E 04
7.48E-01	6.[illegible]3E 02	5.204E-08	2.370E-09	-4.874E-11	-2.297E-12	1.725E-04	-1.45E-05	4.57E 02	2.51E-03	-5.06E 00	-1.16E 03	-2.23E 04	-2.16E 04
8.24E-01	4.43E 02	3.185E-08	1.461E-09	-4.821E-11	-2.274E-12	8.342E-05	-4.92E-06	4.07E 02	1.13E-03	-5.37E 00	-1.24E 03	-3.16E 04	-3.12E 04
9.08E-01	2.32E 02	1.447E-08	6.678E-10	-4.789E-11	-2.261E-12	2.299E-05	-7.17E-07	3.05E 02	2.83E-04	-7.24E 00	-1.69E 03	-5.99E 04	-5.96E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-4.781E-11	-2.258E-12	0.000E-39	0.00E-39	9.28E 01	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38

TABLE I MACH NUMBER 8 (Contd) (3)

X = 100.00 DELTA Z = 0.3981 ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	KPLUS *PHIY	D PLUS *SY/S	O MINUS *SY/S	OTPLUS *SY/S	OTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	3.598E-09	4.094E-09	4.256E-01	-9.50E-02	0.00E-39	4.76E 00	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.35E-04	1.88E 04	4.053E-05	2.714E-07	7.508E-10	1.246E-09	4.238E-01	-9.47E-02	5.53E-01	4.60E 00	9.73E 02	4.14E 05	6.93E 02	1.26E 03
1.75E-03	2.76E 04	4.415E-05	3.888E-07	6.717E-11	5.618E-10	4.206E-01	-9.43E-02	1.27E 00	4.50E 00	4.53E 01	1.28E 05	7.73E 01	9.29E 02
2.76E-03	3.26E 04	4.513E-05	4.504E-07	-2.197E-10	2.738E-10	4.168E-01	-9.38E-02	2.10E 00	4.39E 00	-1.08E 02	5.28E 04	-3.19E 02	6.55E 02
3.88E-03	3.58E 04	4.256E-05	4.849E-07	-3.534E-10	1.389E-10	4.128E-01	-9.34E-02	3.03E 00	4.29E 00	[illegible] 02	2.48E 04	-5.80E 02	4.72E 02
5.10E-03	3.78E 04	3.974E-05	5.049E-07	-4.212E-10	6.972E-11	4.085E-01	-9.29E-02	4.11E 00	4.21E 00	-1.24E 02	1.22E 04	-7.69E 02	3.24E 02
6.45E-03	3.93E 04	3.703E-05	5.162E-07	-4.582E-10	3.136E-11	4.041E-01	-9.23E-02	5.32E 00	4.12E 00	-1.10E 02	5.75E 03	-9.16E 02	2.04E 02
7.94E-03	4.03E 04	3.451E-05	5.219E-07	-4.790E-10	9.069E-12	3.995E-01	-9.17E-02	6.66E 00	4.04E 00	-9.67E 01	2.24E 03	-1.04E 03	1.03E 02
9.57E-03	4.10E 04	3.220E-05	5.239E-07	-4.909E-10	-4.399E-12	3.947E-01	-9.11E-02	8.15E 00	3.95E 00	-8.44E 01	2.33E 02	-1.14E 03	1.35E 01
1.14E-02	4.15E 04	3.007E-05	5.231E-07	-4.973E-10	-1.252E-11	3.898E-01	-9.04E-02	9.85E 00	3.87E 00	-7.39E 01	-9.25E 02	-1.24E 03	-5.65E 01
1.34E-02	4.18E 04	2.812E-05	5.203E-07	-5.006E-10	-1.760E-11	3.846E-01	-8.96E-02	1.17E 01	3.78E 00	-6.49E 01	-1.62E 03	-1.34E 03	-1.42E 02
1.55E-02	4.20E 04	2.630E-05	5.158E-07	-5.017E-10	-2.061E-11	3.792E-01	-8.88E-02	1.38E 01	3.70E 00	-5.71E 01	-2.01E 03	-1.43E 03	-2.14E 02
1.79E-02	4.21E 04	2.462E-05	5.101E-07	-5.014E-10	-2.231E-11	3.736E-01	-8.79E-02	1.61E 01	3.61E 00	-5.03E 01	-2.20E 03	-1.51E 03	-2.83E 02
2.06E-02	4.21E 04	2.305E-05	5.033E-07	-5.002E-10	-2.320E-11	3.677E-01	-8.69E-02	1.87E 01	3.52E 00	-4.45E 01	-2.29E 03	-1.60E 03	-3.57E 02
2.35E-02	4.20E 04	2.159E-05	4.955E-07	-4.984E-10	-2.366E-11	3.616E-01	-8.58E-02	2.15E 01	3.43E 00	-3.96E 01	-2.32E 03	-1.67E 03	-4.22E 02
2.67E-02	4.13E 04	2.021E-05	4.870E-07	-4.963E-10	-2.386E-11	3.552E-01	-8.47E-02	2.47E 01	3.34E 00	-3.54E 01	-2.31E 03	-1.74E 03	-4.97E 02
3.02E-02	4.15E 04	1.891E-05	4.776E-07	-4.938E-10	-2.392E-11	3.485E-01	-8.35E-02	2.81E 01	3.24E 00	-3.16E 01	-2.29E 03	-1.87E 03	-5.78E 02
3.41E-02	4.14E 04	1.769E-05	4.673E-07	-4.911E-10	-2.390E-11	3.416E-01	-8.21E-02	3.19E 01	3.14E 00	-2.92E 01	-2.24E 03	-1.97E 03	-6.47E 02
3.84E-02	4.11E 04	1.653E-05	4.562E-07	-4.883E-10	-2.384E-11	3.343E-01	-8.07E-02	3.61E 01	3.04E 00	-2.72E 01	-2.19E 03	-2.06E 03	-7.65E 02
4.31E-02	4.05E 04	1.544E-05	4.443E-07	-4.852E-10	-2.375E-11	3.267E-01	-7.91E-02	4.07E 01	2.94E 00	-2.26E 01	-2.13E 03	-2.17E 03	-8.73E 02
4.82E-02	4.01E 04	1.440E-05	4.315E-07	-4.820E-10	-2.365E-11	3.188E-01	-7.74E-02	4.58E 01	2.84E 00	-2.03E 01	-2.07E 03	-2.28E 03	-9.72E 02
5.39E-02	3.96E 04	1.341E-05	4.179E-07	-4.786E-10	-2.352E-11	3.106E-01	-7.57E-02	5.14E 01	2.73E 00	-1.83E 01	-2.01E 03	-2.39E 03	-1.12E 03
6.02E-02	3.89E 04	1.248E-05	4.035E-07	-4.750E-10	-2.339E-11	3.020E-01	-7.37E-02	5.75E 01	2.62E 00	-1.64E 01	-1.94E 03	-2.51E 03	-1.26E 03
6.71E-02	3.82E 04	1.159E-05	3.982E-07	-4.712E-10	-2.324E-11	2.930E-01	-7.17E-02	6.42E 01	2.51E 00	-1.48E 01	-1.85E 03	-2.64E 03	-1.42E 03
7.47E-02	3.75E 04	1.074E-05	3.722E-07	-4.672E-10	-2.308E-11	2.837E-01	-6.95E-02	7.16E 01	2.40E 00	-1.33E 01	-1.79E 03	-2.77E 03	-1.57E 03
8.31E-02	3.64E 04	9.937E-06	3.555E-07	-4.630E-10	-2.290E-11	2.740E-01	-6.72E-02	7.97E 01	2.29E 00	-1.21E 01	-1.71E 03	-2.92E 03	-1.73E 03
9.23E-02	3.53E 04	9.173E-06	3.382E-07	-4.586E-10	-2.271E-11	2.640E-01	-6.47E-02	8.85E 01	2.17E 00	-1.09E 01	-1.63E 03	-3.07E 03	-1.97E 03
1.02E-01	3.42E 04	8.447E-06	3.203E-07	-4.539E-10	-2.251E-11	2.536E-01	-6.21E-02	9.82E 01	2.06E 00	-9.83E 00	-1.55E 03	-3.23E 03	-2.18E 03
1.14E-01	3.30E 04	7.756E-06	3.020E-07	-4.491E-10	-2.229E-11	2.428E-01	-5.93E-02	1.09E 02	1.94E 00	-8.93E 00	-1.47E 03	-3.42E 03	-2.41E 03
1.26E-01	3.15E 04	7.100E-06	2.834E-07	-4.441E-10	-2.206E-11	2.317E-01	-5.64E-02	1.20E 02	1.82E 00	-8.09E 00	-1.39E 03	-3.62E 03	[illegible]
1.39E-01	3.03E 04	6.478E-06	2.646E-07	-4.389E-10	-2.181E-11	2.203E-01	-5.33E-02	1.33E 02	1.70E 00	-7.31E 00	-1.31E 03	-3.83E 03	-2.73E 03
1.54E-01	2.89E 04	5.889E-06	2.456E-07	-4.335E-10	-2.154E-11	2.086E-01	-5.01E-02	1.46E 02	1.58E 00	-6.58E 00	-1.22E 03	-4.05E 03	-3.21E 03
1.71E-01	2.75E 04	5.433E-06	2.267E-07	-4.279E-10	-2.127E-11	1.966E-01	-4.68E-02	1.60E 02	1.46E 00	-5.92E 00	-1.14E 03	-4.29E 03	-3.52E 03
1.89E-01	2.60E 04	4.909E-06	2.080E-07	-4.221E-10	-2.097E-11	1.842E-01	-4.34E-02	1.76E 02	1.34E 00	-5.33E 00	-1.05E 03	-4.56E 03	-3.85E 03
2.09E-01	2.45E 04	4.317E-06	1.897E-07	-4.162E-10	-2.067E-11	1.716E-01	-3.98E-02	1.92E 02	1.22E 00	-4.80E 00	-9.74E 02	-4.85E 03	-4.21E 03
2.30E-01	2.29E 04	3.954E-06	1.717E-07	-4.101E-10	-2.036E-11	1.588E-01	-3.62E-02	2.09E 02	1.10E 00	-4.24E 00	-9.01E 02	-5.18E 03	-4.59E 03
2.59E-01	2.14E 04	3.420E-06	1.543E-07	-4.040E-10	-2.003E-11	1.459E-01	-3.26E-02	2.26E 02	9.92E-01	-3.92E 00	-8.30E 02	-5.55E 03	-5.02E 03
2.81E-01	1.98E 04	3.215E-06	1.375E-07	-3.977E-10	-1.970E-11	1.326E-01	-2.89E-02	2.45E 02	8.80E-01	-3.53E 00	-7.60E 02	-5.96E 03	-5.47E 03
3.10E-01	1.83E 04	2.538E-06	1.215E-07	-3.914E-10	-1.936E-11	1.194E-01	-2.52E-02	2.64E 02	7.71E-01	-3.17E 00	-6.95E 02	-6.42E 03	-6.01E 03
3.42E-01	1.67E 04	2.289E-06	1.063E-07	-3.851E-10	-1.902E-11	1.061E-01	-2.16E-02	2.83E 02	6.65E-01	-2.86E 00	-6.34E 02	-6.96E 03	-6.50E 03
3.78E-01	1.52E 04	1.965E-06	9.191E-08	-3.788E-10	-1.868E-11	9.289E-02	-1.81E-02	3.02E 02	5.65E-01	-2.58E 00	-5.78E 02	-7.59E 03	-7.29E 03
4.17E-01	1.36E 04	1.667E-06	7.945E-08	-3.726E-10	-1.833E-11	7.984E-02	-1.47E-02	3.22E 02	4.70E-01	-2.34E 00	-5.29E 02	-8.25E 03	-8.06E 03
4.59E-01	1.21E 04	1.394E-06	6.590E-08	-3.666E-10	-1.800E-11	6.710E-02	-1.16E-02	3.41E 02	3.82E-01	-2.13E 00	-4.87E 02	-9.27E 03	-9.06E 03
5.06E-01	1.05E 04	1.143E-06	5.430E-08	-3.608E-10	-1.768E-11	5.479E-02	-8.72E-03	3.56E 02	3.00E-01	-1.95E 00	-4.47E 02	-1.03E 04	-1.03E 04
5.58E-01	9.12E 03	9.167E-07	4.366E-08	-3.555E-10	-1.738E-11	4.306E-02	-6.19E-03	3.66E 02	2.25E-01	-1.78E 00	-4.11E 02	-1.20E 04	-1.18E 04
6.15E-01	7.67E 03	7.116E-07	3.400E-08	-3.507E-10	-1.711E-11	3.211E-02	-4.05E-03	3.68E 02	1.59E-01	-1.64E 00	-3.80E 02	-1.40E 04	-1.39E 04
6.78E-01	6.23E 03	5.786E-07	2.532E-08	-3.465E-10	-1.687E-11	2.216E-02	-2.35E-03	3.61E 02	1.04E-01	-1.54E 00	-3.58E 02	-1.70E 04	-1.67E 04
7.48E-01	4.78E 03	3.567E-07	1.760E-08	-3.430E-10	-1.667E-11	1.351E-02	-1.13E-03	3.38E 02	5.91E-02	-1.51E 00	-3.51E 02	-2.19E 04	-2.18E 04
8.24E-01	3.28E 03	2.250E-07	1.081E-08	-3.404E-10	-1.652E-11	6.541E-03	-3.86E-04	3.02E 02	2.65E-02	-1.61E 00	-3.75E 02	-3.15E 04	-3.14E 04
9.08E-01	1.71E 03	1.024E-07	4.929E-09	-3.389E-10	-1.643E-11	1.805E-03	-5.63E-05	2.26E 02	6.65E-03	-2.17E 00	-5.07E 02	[illegible]	-5.97E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-3.385E-10	-1.640E-11	0.000E-39	0.00E-39	6.86E 01	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38

TABLE II MACH NUMBER 10 (1)

X = 5.62 DELTA Z = 0.7952 ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	XPLUS *PHIY	C PLUS *SY/S	D MINUS *SY/S	DTPLUS *SY/S	DTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	4.514E-06	4.997E-06	2.948E 00	-5.00E-01	0.00E-39	2.76E 02	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.55E-04	3.07E 05	1.026E-04	5.219E-07	2.632E-06	3.115E-06	2.945E 00	-5.97E-01	1.25E 00	2.70E 02	2.48E 04	6.37E 06	2.0[illegible]E 03	2.24E 03
1.75E-03	5.54E 06	1.675E-04	3.188E-07	1.750E-06	2.232E-06	2.937E 00	-5.95E-01	2.90E 00	2.66E 02	8.84E 03	2.58E 06	1.73E 03	2.13E 03
2.76E-03	7.65E 06	2.109E-04	1.243E-06	1.204E-06	1.684E-06	2.923E 00	-5.92E-01	4.74E 00	2.63E 02	4.16E 03	1.93E 06	1.37E 03	2.05E 03
3.88E-03	9.55E 06	2.394E-04	1.532E-06	8.189E-07	1.298E-06	2.905E 00	-5.87E-01	6.68E 00	2.59E 02	2.11E 03	9.07E 05	1.05E 03	1.74E 03
5.10E-03	1.13E 07	2.573E-04	1.780E-06	5.221E-07	9.996E-07	2.884E 00	-5.85E-01	9.30E 00	2.55E 02	1.33E 03	6.12E 05	7.11E 02	1.81E 03
6.45E-03	1.2[illegible]E 07	2.669E-04	1.994E-06	2.825E-07	7.580E-07	2.858E 00	-5.81E-01	1.23E 01	2.51E 02	4.00E 02	4.26E 05	3.67E 02	1.57E 03
7.94E-03	1.42E 07	2.701E-04	2.187E-06	9.014E-08	5.633E-07	2.829E 00	-5.77E-01	1.51E 01	2.47E 02	2.71E 01	3.04E 05	3.13E 01	1.53E 03
9.57E-03	1.55E 07	2.685E-04	2.352E-06	-6.430E-08	4.063E-07	2.796E 00	-5.72E-01	1.85E 01	2.42E 02	-1.97E 02	2.19E 05	-2.91E 02	1.29E 03
1.14E-02	1.65E 07	2.632E-04	2.494E-06	-1.864E-07	2.812E-07	2.760E 00	-5.67E-01	2.24E 01	2.38E 02	-3.27E 02	1.60E 05	-5.93E 02	1.23E 03
1.34E-02	1.75E 07	2.553E-04	2.615E-06	-2.821E-07	1.823E-07	2.721E 00	-5.62E-01	2.67E 01	2.33E 02	-3.99E 02	1.16E 05	-8.87E 02	1.12E 03
1.55E-02	1.85E 07	2.456E-04	2.710E-06	-3.552E-07	1.058E-07	2.679E 00	-5.56E-01	3.13E 01	2.27E 02	-4.31E 02	8.79E 04	-1.16E 03	1.01E 03
1.79E-02	1.93E 07	2.347E-04	2.804E-06	-4.094E-07	4.790E-08	2.634E 00	-5.50E-01	3.68E 01	2.22E 02	-4.37E 02	6.64E 04	-1.40E 03	9.13E 02
2.06E-02	2.01E 07	2.231E-04	2.886E-06	-4.485E-07	4.802E-09	2.587E 00	-5.43E-01	4.26E 01	2.16E 02	-4.27E 02	5.12E 04	-1.63E 03	8.35E 02
2.35E-02	2.08E 07	2.111E-04	2.953E-06	-4.770E-07	-2.789E-08	2.537E 00	-5.35E-01	4.93E 01	2.10E 02	-4.10E 02	4.05E 04	-1.85E 03	7.72E 02
2.67E-02	2.15E 07	1.990E-04	3.012E-06	-4.969E-07	-5.230E-08	2.484E 00	-5.27E-01	5.65E 01	2.04E 02	-3.87E 02	3.18E 04	-2.06E 03	7.22E 02
3.02E-02	2.21E 07	1.871E-04	3.064E-06	-5.097E-07	-6.934E-08	2.429E 00	-5.19E-01	6.45E 01	1.98E 02	-3.62E 02	2.59E 04	-2.25E 03	[illegible]
3.41E-02	2.28E 07	1.753E-04	3.111E-06	-5.166E-07	-8.199E-08	2.371E 00	-5.09E-01	7.33E 01	1.92E 02	-3.35E 02	2.13E 04	-2.45E 03	6.74E 02
3.84E-02	2.34E 07	1.639E-04	3.155E-06	-5.196E-07	-9.006E-08	2.311E 00	-4.99E-01	8.30E 01	1.85E 02	-3.08E 02	1.86E 04	-2.63E 03	6.73E 02
4.31E-02	2.41E 07	1.528E-04	3.197E-06	-5.194E-07	-9.530E-08	2.249E 00	-4.89E-01	9.38E 01	1.79E 02	-2.83E 02	1.63E 04	-2.81E 03	6.92E 02
4.82E-02	2.47E 07	1.422E-04	3.238E-06	-5.169E-07	-9.868E-08	2.184E 00	-4.77E-01	1.05E 02	1.72E 02	-2.60E 02	1.46E 04	-2.99E 03	7.16E 02
5.39E-02	2.55E 07	1.321E-04	3.278E-06	-5.129E-07	-1.007E-07	2.117E 00	-4.65E-01	1.19E 02	1.66E 02	-2.38E 02	1.32E 04	-3.17E 03	7.42E 02
6.02E-02	2.62E 07	1.223E-04	3.318E-06	-5.077E-07	-1.018E-07	2.047E 00	-4.52E-01	1.33E 02	1.59E 02	-2.17E 02	1.19E 04	-3.34E 03	7.90E 02
6.71E-02	2.70E 07	1.131E-04	3.357E-06	-5.016E-07	-1.022E-07	1.979E 00	-4.38E-01	1.48E 02	1.51E 02	-1.97E 02	1.08E 04	-3.55E 03	8.29E 02
7.47E-02	2.73E 07	1.043E-04	3.395E-06	-4.949E-07	-1.023E-07	1.901E 00	-4.23E-01	1.65E 02	1.44E 02	-1.79E 02	9.65E 03	-3.73E 03	8.55E 02
8.31E-02	2.87E 07	9.590E-05	3.432E-06	-4.877E-07	-1.022E-07	1.824E 00	-4.08E-01	1.83E 02	1.36E 02	-1.63E 02	8.57E 03	-3.94E 03	8.92E 02
9.23E-02	2.96E 07	8.798E-05	3.467E-06	-4.801E-07	-1.018E-07	1.745E 00	-3.91E-01	2.02E 02	1.29E 02	-1.47E 02	7.51E 03	-4.18E 03	9.09E 02
1.02E-01	3.05E 07	8.047E-05	3.498E-06	-4.721E-07	-1.014E-07	1.664E 00	-3.74E-01	2.24E 02	1.21E 02	-1.34E 02	6.44E 03	-4.41E 03	9.08E 02
1.14E-01	3.14E 07	7.338E-05	3.524E-06	-4.658E-07	-1.009E-07	1.581E 00	-3.56E-01	2.48E 02	1.13E 02	-1.22E 02	5.35E 03	-4.67E 03	9.78E 02
1.26E-01	3.23E 07	6.667E-05	3.542E-06	-4.552E-07	-1.002E-07	1.497E 00	-3.37E-01	2.74E 02	1.06E 02	-1.11E 02	4.27E 03	-4.93E 03	9.17E 02
1.39E-01	3.32E 07	6.035E-05	3.550E-06	-4.465E-07	-9.947E-08	1.411E 00	-3.17E-01	3.01E 02	9.80E 01	-1.00E 02	3.20E 03	-5.24E 03	7.16E 02
1.54E-01	3.41E 07	5.440E-05	3.544E-06	-4.374E-07	-9.861E-08	1.329E 00	-2.97E-01	3.30E 02	9.03E 01	-9.05E 01	2.16E 03	-5.55E 03	5.66E 02
1.71E-01	3.49E 07	4.883E-05	3.526E-06	-4.281E-07	-9.761E-08	1.237E 00	-2.76E-01	3.62E 02	8.27E 01	-8.15E 01	1.15E 03	-5.90E 03	3.35E 02
1.89E-01	3.56E 07	4.363E-05	3.487E-06	-4.185E-07	-9.647E-08	1.149E 00	-2.54E-01	3.95E 02	7.51E 01	-7.33E 01	1.89E 02	-6.25E 03	6.92E 01
2.09E-01	3.52E 07	3.878E-05	3.426E-06	-4.089E-07	-9.516E-08	1.059E 00	-2.32E-01	4.30E 02	6.77E 01	-6.59E 01	-7.11E 02	-6.67E 03	-3.07E 02
2.30E-01	3.65E 07	3.427E-05	3.338E-06	-3.991E-07	-9.369E-08	9.696E-01	-2.10E-01	4.66E 02	6.05E 01	-5.92E 01	-1.54E 03	-7.11E 03	-7.90E 02
2.55E-01	3.67E 07	3.009E-05	3.223E-06	-3.892E-07	-9.202E-08	8.808E-01	-1.88E-01	5.04E 02	5.36E 01	-5.32E 01	-2.27E 03	-7.61E 03	-1.39E 03
2.81E-01	3.63E 07	2.624E-05	3.077E-06	-3.793E-07	-9.016E-08	7.929E-01	-1.66E-01	5.43E 02	4.69E 01	-4.76E 01	-2.89E 03	-8.15E 03	-2.12E 03
3.10E-01	3.59E 07	2.269E-05	2.900E-06	-3.693E-07	-8.811E-08	7.061E-01	-1.44E-01	5.83E 02	4.06E 01	-4.26E 01	-3.41E 03	-8.79E 03	-3.00E 03
3.42E-01	3.50E 07	1.945E-05	2.693E-06	-3.595E-07	-8.587E-08	6.210E-01	-1.23E-01	6.24E 02	3.45E 01	-3.61E 01	-3.82E 03	-9.52E 03	-4.08E 03
3.78E-01	3.36E 07	1.649E-05	2.456E-06	-3.498E-07	-8.347E-08	5.303E-01	-1.02E-01	6.63E 02	2.88E 01	-3.39E 01	-4.11E 03	-1.04E 04	-5.30E 03
4.17E-01	3.17E 07	1.380E-05	2.195E-06	-3.403E-07	-8.094E-08	4.583E-01	-8.30E-02	7.01E 02	2.36E 01	-3.05E 01	-4.29E 03	-1.14E 04	-6.95E 03
4.59E-01	2.93E 07	1.137E-05	1.917E-0[illegible]	[illegible].313E-07	-7.834E-08	3.819E-01	-6.50E-02	7.35E 02	1.90E 01	-2.75E 01	-4.38E 03	1.26E 04	-8.60E 03
5.05E-01	2.67E 07	9.188E-06	1.630E-[illegible]	[illegible].229E-07	-7.574E-08	3.095E-01	-4.88E-02	7.54E 02	1.47E 01	-2.48E 01	-4.37E 03	-1.42E 04	-1.07E 04
5.58E-01	2.33E 07	7.249E-06	1.343E-06	-3.153E-07	-7.321E-08	2.417E-01	-3.45E-02	7.53E 02	1.10E 01	-2.22E 01	-4.26E 03	-1.61E 04	-1.32E 04
6.15E-01	2.06E 07	5.541E-06	1.063E-06	-3.084E-07	-7.080E-08	1.793E-01	-2.25E-02	7.35E 02	7.69E 00	-2.01E 01	-4.11E 03	-1.67E 04	-1.53E 04
6.78E-01	1.70E 07	4.048E-06	7.990E-07	-3.025E-07	-6.860E-08	1.232E-01	-1.31E-02	6.92E 02	4.96E 00	-1.85E 01	-3.97E 03	-2.26E 04	-2.07E 04
7.48E-01	1.33E 07	2.757E-06	5.563E-07	-2.977E-07	-6.673E-08	7.504E-02	-6.32E-03	6.07E 02	2.80E 00	-1.75E 01	-3.90E 03	-2.89E 04	-2.74E 04
8.24E-01	9.29E 06	1.657E-06	3.401E-07	-2.944E-07	-6.529E-08	3.647E-02	-2.16E-03	4.63E 02	1.24E 00	-1.78E 01	-4.06E 03	-4.11E 04	-4.00E 04
9.08E-01	4.97E 06	7.381E-07	1.536E-07	-2.927E-07	-6.441E-08	1.014E-02	-3.17E-04	2.08E 02	3.09E-01	-2.76E 01	-5.23E 03	-7.56E 04	-7.59E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-2.924E-07	-6.414E-08	0.000E-39	0.00E-39	-2.35E 02	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38

TABLE II MACH NUMBER 10 (Contd) (2)

X = 22.20 DELTA Z = 0.7962 ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	KPLUS *PHIY	D PLUS *SY/S	I MINUS *SY/S	DTPLUS *SY/S	DTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	1.312E-05	1.310E-05	3.684E 01	-8.48E-01	0.00E-39	1.15E 03	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.35E-04	2.45E 07	7.976E-04	4.136E-06	7.480E-06	7.456E-06	3.661E 01	-8.17E-01	9.53E-01	1.12E 03	7.05E 03	2.16E 06	1.74E 03	2.29E 03
1.75E-03	4.49E 07	1.170E-03	7.445E-06	4.835E-06	4.808E-06	3.604E 01	-7.84E-01	2.20E 00	1.09E 03	2.01E 03	9.22E 05	1.16E 03	2.31E 03
2.76E-03	6.41E 07	1.343E-03	1.045E-05	3.197E-06	3.166E-06	3.524E 01	-7.48E-01	3.62E 00	1.05E 03	6.82E 02	5.53E 05	6.63E 02	2.37E 03
3.88E-03	8.36E 07	1.411E-03	1.316E-05	2.043E-06	2.007E-06	3.426E 01	-7.09E-01	5.23E 00	1.02E 03	1.71E 02	3.86E 05	2.56E 02	2.47E 03
5.10E-03	1.04E 08	1.420E-03	1.635E-05	1.154E-06	1.111E-06	3.315E 01	-6.68E-01	7.05E 00	9.77E 02	-5.91E 01	2.93E 05	-1.23E 02	2.60E 03
6.45E-03	1.26E 08	1.393E-03	1.955E-05	4.367E-07	3.866E-07	3.191E 01	-6.24E-01	9.13E 00	9.34E 02	-1.70E 02	2.35E 05	-4.58E 02	2.77E 03
7.94E-03	1.49E 08	1.344E-03	2.298E-05	-1.395E-07	-1.972E-07	3.058E 01	-5.77E-01	1.15E 01	8.89E 02	-2.20E 02	1.97E 05	-7.80E 02	2.98E 03
9.57E-03	1.76E 08	1.283E-03	2.680E-05	-6.024E-07	-6.682E-07	2.915E 01	-5.29E-01	1.41E 01	8.42E 02	-2.39E 02	1.70E 05	-1.06E 03	3.23E 03
1.14E-02	2.07E 08	1.216E-03	3.115E-05	-9.686E-07	-1.043E-06	2.756E 01	-4.77E-01	1.70E 01	7.93E 02	-2.40E 02	1.51E 05	-1.32E 03	3.53E 03
1.34E-02	2.43E 08	1.146E-03	3.619E-05	-1.256E-06	-1.339E-06	2.607E 01	-4.24E-01	2.03E 01	7.43E 02	-2.32E 02	1.36E 05	-1.55E 03	3.87E 03
1.55E-02	2.87E 08	1.076E-03	4.214E-05	-1.475E-06	-1.568E-06	2.446E 01	-3.69E-01	2.39E 01	6.92E 02	-2.18E 02	1.23E 05	-1.76E 03	4.25E 03
1.79E-02	3.39E 08	1.007E-03	4.919E-05	-1.639E-06	-1.741E-06	2.277E 01	-3.12E-01	2.77E 01	6.39E 02	-2.01E 02	1.13E 05	-1.94E 03	4.65E 03
2.06E-02	4.02E 08	9.410E-04	5.767E-05	-1.757E-06	-1.869E-06	2.103E 01	-2.55E-01	3.24E 01	5.86E 02	-1.84E 02	1.03E 05	-2.11E 03	5.05E 03
2.35E-02	4.73E 08	8.779E-04	6.784E-05	-1.844E-06	-1.965E-06	1.925E 01	-1.96E-01	3.74E 01	5.32E 02	-1.67E 02	9.33E 04	-2.26E 03	5.41E 03
2.67E-02	5.71E 08	8.182E-04	7.999E-05	-1.905E-06	-2.035E-06	1.744E 01	-1.37E-01	4.30E 01	4.78E 02	-1.51E 02	8.37E 04	-2.41E 03	5.71E 03
3.02E-02	6.82E 08	7.518E-04	9.438E-05	-1.945E-06	-2.085E-06	1.561E 01	-7.91E-02	4.90E 01	4.24E 02	-1.36E 02	7.41E 04	-2.55E 03	5.93E 03
3.41E-02	8.14E 08	7.087E-04	1.112E-04	-1.968E-06	-2.117E-06	1.377E 01	-2.22E-02	5.57E 01	3.71E 02	-1.22E 02	6.45E 04	-2.67E 03	6.03E 03
3.84E-02	9.63E 08	6.590E-04	1.304E-04	-1.978E-06	-2.134E-06	1.194E 01	3.27E-02	6.31E 01	3.19E 02	-1.09E 02	5.48E 04	-2.80E 03	5.79E 03
4.31E-02	1.14E 09	6.123E-04	1.518E-04	-1.979E-06	-2.141E-06	1.015E 01	8.45E-02	7.12E 01	2.69E 02	-9.83E 01	4.54E 04	-2.92E 03	5.77E 03
4.82E-02	1.34E 09	5.684E-04	1.747E-04	-1.973E-06	-2.140E-06	8.421E 00	1.32E-01	8.02E 01	2.22E 02	-8.84E 01	3.64E 04	-3.05E 03	5.37E 03
5.39E-02	1.54E 09	5.273E-04	1.980E-04	-1.963E-06	-2.131E-06	6.788E 00	1.76E-01	9.00E 01	1.77E 02	-7.95E 01	2.79E 04	-3.18E 03	4.78E 03
6.02E-02	1.74E 09	4.866E-04	2.205E-04	-1.949E-06	-2.116E-06	5.279E 00	2.13E-01	1.01E 02	1.36E 02	-7.14E 01	2.02E 04	-3.32E 03	4.02E 03
6.71E-02	1.95E 09	4.521E-04	2.404E-04	-1.932E-06	-2.095E-06	3.923E 00	2.45E-01	1.12E 02	1.00E 02	-6.42E 01	1.34E 04	-3.47E 03	3.11E 03
7.47E-02	2.10E 09	4.178E-04	2.561E-04	-1.914E-06	-2.069E-06	2.741E 00	2.70E-01	1.25E 02	6.92E 01	-5.78E 01	7.81E 03	-3.63E 03	2.10E 03
8.31E-02	2.23E 09	3.854E-04	2.665E-04	-1.895E-06	-2.040E-06	1.747E 00	2.89E-01	1.39E 02	4.35E 01	-5.21E 01	3.29E 03	-3.81E 03	1.02E 03
9.23E-02	2.31E 09	3.547E-04	2.706E-04	-1.873E-06	-2.008E-06	9.408E-01	3.01E-01	1.54E 02	2.31E 01	-4.70E 01	-1.24E 02	-4.00E 03	-4.51E 01
1.02E-01	2.35E 09	3.258E-04	2.692E-04	-1.851E-06	-1.975E-06	3.140E-01	3.07E-01	1.70E 02	7.61E 00	-4.24E 01	-2.56E 03	-4.20E 03	-1.08E 03
1.14E-01	2.34E 09	2.984E-04	2.621E-04	-1.927E-06	-1.940E-06	-1.506E-01	3.09E-01	1.83E 02	-3.60E 00	-3.85E 01	-4.17E 03	-4.44E 03	-2.05E 03
1.26E-01	2.29E 09	2.724E-04	2.505E-04	-1.803E-06	-1.905E-06	-4.764E-01	3.04E-01	2.00E 02	-1.12E 01	-3.50E 01	-5.11E 03	-4.70E 03	-2.92E 03
1.39E-01	2.20E 09	2.478E-04	2.354E-04	-1.778E-06	-1.872E-06	-6.891E-01	2.96E-01	2.27E 02	-1.60E 01	-3.17E 01	-5.55E 03	-4.98E 03	-3.72E 03
1.54E-01	2.10E 09	2.246E-04	2.184E-04	-1.751E-06	-1.828E-06	-8.137E-01	2.84E-01	2.51E 02	-1.85E 01	-2.86E 01	-5.62E 03	-5.26E 03	-4.42E 03
1.71E-01	1.99E 09	2.026E-04	2.004E-04	-1.724E-06	-1.805E-06	-8.724E-01	2.71E-01	2.75E 02	-1.94E 01	-2.58E 01	-5.45E 03	-5.60E 03	-5.05E 03
1.89E-01	1.86E 09	1.821E-04	1.824E-04	-1.697E-06	-1.773E-06	-8.839E-01	2.55E-01	3.00E 02	-1.93E 01	-2.32E 01	-5.13E 03	-5.90E 03	-5.52E 03
2.09E-01	1.74E 09	1.627E-04	1.542E-04	-1.668E-06	-1.742E-06	-8.634E-01	2.37E-01	3.27E 02	-1.84E 01	-2.09E 01	-4.75E 03	-6.35E 03	-6.10E 03
2.30E-01	1.60E 09	1.446E-04	1.46[illegible]E-04	-1.639E-06	-1.710E-06	-8.222E-01	2.19E-01	3.54E 02	-1.71E 01	-1.88E 01	-4.34E 03	-6.79E 03	-6.68E 03
2.55E-01	1.48E 09	1.278E-04	1.297E-04	-1.610E-06	-1.680E-06	-7.687E-01	2.00E-01	3.83E 02	-1.56E 01	-1.69E 01	-3.93E 03	-7.27E 03	-7.21E 03
2.81E-01	1.35E 09	1.120E-04	1.131E-04	-1.581E-06	-1.649E-06	-7.087E-01	1.80E-01	4.13E 02	-1.40E 01	-1.52E 01	-3.54E 03	-7.82E 03	-7.78E 03
3.10E-01	1.23E 09	9.749E-05	9.9[illegible]E-05	-1.551E-06	-1.619E-06	-6.463E-01	1.60E-01	4.43E 02	-1.24E 01	-1.36E 01	-3.18E 03	-8.44E 03	-8.40E 03
3.42E-01	1.11E 09	8.404E-05	8.540E-05	-1.522E-06	-1.589E-06	-5.841E-01	1.41E-01	4.74E 02	-1.08E 01	-1.22E 01	-2.95E 03	-9.17E 03	-9.11E 03
3.78E-01	9.95E 08	7.166E-05	7.280E-05	-1.492E-06	-1.560E-06	-5.234E-01	1.21E-01	5.04E 02	-9.32E 00	-1.09E 01	-2.54E 03	-1.00E 04	-9.94E 03
4.17E-01	8.84E 08	6.032E-05	6.128E-05	-1.464E-06	-1.532E-06	-4.645E-01	1.02E-01	5.33E 02	-7.98E 00	-9.84E 00	-2.29E 03	-1.10E 04	-1.09E 04
4.59E-01	7.77E 08	4.798E-05	5.078E-05	-1.437E-06	-1.504E-06	-4.072E-01	8.32E-02	5.59E 02	-6.74E 00	-8.91E 00	-2.07E 03	1.[illegible]3E 04	-1.22E 04
5.06E-01	6.76E 08	4.061E-05	4.129E-05	-1.411E-06	-1.479E-06	-3.505E-01	6.54E-02	5.73E 02	-5.56E 00	-8.06E 00	-1.87E 03	-1.39E 04	-1.37E 04
5.58E-01	5.81E 08	3.220E-05	3.278E-05	-1.388E-06	-1.457E-06	-2.934E-01	4.87E-02	5.72E 02	-4.43E 00	-7.26E 00	-1.66E 03	-1.58E 04	-1.56E 04
6.15E-01	4.88E 08	2.473E-05	2.522E-05	-1.368E-06	-1.437E-06	-2.351E-01	3.37E-02	5.58E 02	-3.36E 00	-6.60E 00	-1.53E 03	-1.84E 04	-1.82E 04
6.78E-01	3.96E 08	1.914E-05	1.859E-05	-1.350E-06	-1.419E-06	-1.760E-01	2.07E-02	5.25E 02	-2.35E 00	-6.09E 00	-1.41E 03	[illegible]	-2.71E 04
7.48E-01	3.04E 08	1.240E-05	1.277E-05	-1.336E-06	-1.406E-06	-1.172E-01	1.06E-02	4.61E 02	-1.46E 00	-5.79E 00	-1.34E 03	-2.86E 04	-2.84E 04
8.24E-01	2.10E 08	7.473E-06	7.69[illegible]E-06	-1.326E-06	-1.397E-06	-6.240E-02	3.87E-03	3.52E 02	-7.08E-01	-5.92E 00	-1.35E 03	-4.09E 04	-4.06E 04
9.08E-01	1.12E 08	3.334E-06	3.456E-06	-1.322E-06	-1.393E-06	-1.895E-02	6.05E-04	1.58E 02	-1.92E-01	-7.53E 00	-1.75E 03	-7.67E 04	-7.64E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-1.321E-06	-1.392E-06	0.000E-39	0.00E-39	-1.79E 02	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38

TABLE II MACH NUMBER 10 (Contd) (3)

X = 100.00 DELTA Z = 0.7962 ETA INTERVALS = 400

ETA	NMINUS	SPLUS	SMINUS	JPLUS	JMINUS	PHIETA	PHI	-V	KPLUS *PHIY	C PLUS *SY/S	D MINUS *SY/S	DTPLUS *SY/S	DTMINUS *SY/S
0.00E-39	0.00E-39	0.000E-39	0.000E-39	4.181E-05	4.179E-05	2.973E 02	-7.24E-01	0.00E-39	2.78E 03	1.00E 38	1.00E 38	1.00E 38	1.00E 38
8.35E-04	1.80E 08	5.457E-03	5.418E-05	2.300E-05	2.297E-05	2.774E 02	-4.82E-01	7.05E-01	2.54E 03	1.05E 03	9.69E 05	8.65E 02	3.42E 03
1.75E-03	1.10E 09	6.704E-03	1.817E-04	1.418E-05	1.414E-05	2.406E 02	-2.44E-01	1.63E 00	2.18E 03	6.38E 01	5.86E 05	1.25E 02	4.89E 03
2.76E-03	2.53E 09	6.137E-03	4.065E-04	8.721E-06	8.668E-06	1.989E 02	-2.19E-02	2.68E 00	1.79E 03	-7.88E 01	4.34E 05	-2.53E 02	6.19E 03
3.88E-03	5.01E 09	5.905E-03	9.024E-04	4.872E-06	4.809E-06	1.560E 02	1.79E-01	3.87E 00	1.39E 03	-9.47E 01	3.24E 05	-4.75E 02	4.93E 03
5.10E-03	8.95E 09	5.655E-03	1.405E-03	1.904E-06	1.831E-06	1.146E 02	3.40E-01	5.23E 00	1.01E 03	-8.65E 01	2.32E 05	-6.05E 02	6.96E 03
6.45E-03	1.39E 10	5.416E-03	2.168E-03	-4.923E-07	-5.689E-07	7.765E 01	4.69E-01	6.76E 00	6.82E 02	-7.62E 01	1.53E 05	-7.01E 02	6.02E 03
7.94E-03	1.92E 10	5.189E-03	2.949E-03	-2.417E-06	-2.492E-06	4.763E 01	5.61E-01	8.49E 00	4.15E 02	-6.81E 01	9.17E 04	-8.03E 02	4.33E 03
9.57E-03	2.35E 10	4.968E-03	3.583E-03	-3.962E-06	-4.032E-06	2.572E 01	6.19E-01	1.04E 01	2.23E 02	-6.26E 01	4.80E 04	-9.28E 02	3.04E 03
1.14E-02	2.65E 10	4.748E-03	3.977E-03	-5.184E-06	-5.247E-06	1.136E 01	6.52E-01	1.23E 01	9.78E 01	-5.90E 01	2.01E 04	-1.03E 03	1.57E 03
1.34E-02	2.74E 10	4.525E-03	4.138E-03	-6.141E-06	-6.198E-06	2.880E 00	6.65E-01	1.50E 01	2.46E 01	-5.49E 01	3.96E 03	-1.24E 03	3.75E 02
1.55E-02	2.81E 10	4.300E-03	4.127E-03	-6.872E-06	-6.924E-06	-1.639E 00	6.65E-01	1.77E 01	-1.39E 01	-5.28E 01	-4.32E 03	-1.42E 03	-4.95E 02
1.79E-02	2.75E 10	4.076E-03	4.008E-03	-7.416E-06	-7.464E-06	-3.771E 00	6.59E-01	2.07E 01	-3.18E 01	-4.95E 01	-8.04E 03	-1.59E 03	-1.10E 03
2.06E-02	2.67E 10	3.853E-03	3.835E-03	-7.808E-06	-7.854E-06	-4.592E 00	6.47E-01	2.40E 01	-3.84E 01	-4.59E 01	-9.31E 03	-1.76E 03	-1.72E 03
2.35E-02	2.56E 10	3.635E-03	3.636E-03	-8.094E-06	-8.139E-06	-4.754E 00	6.34E-01	2.77E 01	-3.94E 01	-4.25E 01	-9.41E 03	-1.92E 03	-1.82E 03
2.67E-02	2.45E 10	3.422E-03	3.430E-03	-8.294E-06	-8.339E-06	-4.619E 00	6.19E-01	3.18E 01	-3.79E 01	-3.91E 01	-8.98E 03	-2.06E 03	-2.04E 03
3.02E-02	2.34E 10	3.216E-03	3.226E-03	-8.424E-06	-8.468E-06	-4.337E 00	6.03E-01	3.63E 01	-3.53E 01	-3.57E 01	-8.35E 03	-2.25E 03	-2.23E 03
3.41E-02	2.22E 10	3.017E-03	3.026E-03	-8.497E-06	-8.541E-06	-4.021E 00	5.87E-01	4.12E 01	-3.25E 01	-3.26E 01	-7.65E 03	-2.36E 03	-2.39E 03
3.84E-02	2.11E 10	2.826E-03	2.834E-03	-8.527E-06	-8.572E-06	-3.702E 00	5.70E-01	4.67E 01	-2.97E 01	-2.95E 01	-6.99E 03	-2.53E 03	-2.55E 03
4.31E-02	2.00E 10	2.643E-03	2.650E-03	-8.526E-06	-8.571E-06	-3.400E 00	5.53E-01	5.27E 01	-2.70E 01	-2.70E 01	-6.37E 03	-2.67E 03	-2.70E 03
4.82E-02	1.89E 10	2.469E-03	2.474E-03	-8.504E-06	-8.548E-06	-3.121E 00	5.37E-01	5.94E 01	-2.46E 01	-2.46E 01	-5.80E 03	-2.83E 03	-2.85E 03
5.39E-02	1.79E 10	2.302E-03	2.306E-03	-8.466E-06	-8.510E-06	-2.863E 00	5.20E-01	6.66E 01	-2.24E 01	-2.23E 01	-5.27E 03	-2.98E 03	-3.01E 03
6.02E-02	1.67E 10	2.142E-03	2.145E-03	-8.416E-06	-8.460E-06	-2.627E 00	5.02E-01	7.45E 01	-2.04E 01	-2.03E 01	-4.78E 03	-3.14E 03	-3.17E 03
6.71E-02	1.60E 10	1.990E-03	1.993E-03	-8.357E-06	-8.401E-06	-2.410E 00	4.85E-01	8.32E 01	-1.85E 01	-1.84E 01	-4.34E 03	-3.31E 03	-3.34E 03
7.47E-02	1.51E 10	1.845E-03	1.849E-03	-8.291E-06	-8.336E-06	-2.214E 00	4.67E-01	9.75E 01	-1.68E 01	-1.66E 01	-3.95E 03	-3.49E 03	-3.52E 03
8.31E-02	1.43E 10	1.707E-03	1.709E-03	-8.221E-06	-8.265E-06	-2.035E 00	4.50E-01	1.03E 02	-1.52E 01	-1.51E 01	-3.57E 03	-3.67E 03	-3.71E 03
9.23E-02	1.35E 10	1.576E-03	1.577E-03	-8.146E-06	-8.191E-06	-1.871E 00	4.32E-01	1.14E 02	-1.38E 01	-1.37E 01	-3.23E 03	-3.87E 03	-3.91E 03
1.02E-01	1.27E 10	1.451E-03	1.452E-03	-8.068E-06	-8.112E-06	-1.722E 00	4.14E-01	1.25E 02	-1.25E 01	-1.24E 01	-2.93E 03	-4.08E 03	-4.13E 03
1.14E-01	1.19E 10	1.332E-03	1.333E-03	-7.988E-06	-8.031E-06	-1.588E 00	3.95E-01	1.39E 02	-1.14E 01	-1.13E 01	-2.66E 03	-4.32E 03	-4.37E 03
1.26E-01	1.11E 10	1.219E-03	1.220E-03	-7.902E-06	-7.946E-06	-1.454E 00	3.76E-01	1.54E 02	-1.03E 01	-1.02E 01	-2.42E 03	-4.56E 03	-4.62E 03
1.39E-01	1.04E 10	1.111E-03	1.112E-03	-7.814E-06	-7.858E-06	-1.348E 00	3.57E-01	1.59E 02	-9.37E 00	-9.26E 00	-2.19E 03	-4.85E 03	-4.90E 03
1.54E-01	9.71E 09	1.010E-03	1.010E-03	-7.723E-06	-7.768E-06	-1.239E 00	3.38E-01	1.86E 02	-8.45E 00	-8.37E 00	-1.98E 03	-5.14E 03	-5.19E 03
1.71E-01	9.05E 09	9.134E-04	9.139E-04	-7.630E-06	-7.675E-06	-1.135E 00	3.19E-01	2.03E 02	-7.59E 00	-7.55E 00	-1.78E 03	-5.46E 03	[illegible]
1.89E-01	8.42E 09	8.227E-04	8.232E-04	-7.534E-06	-7.579E-06	-1.038E 00	2.99E-01	2.22E 02	-6.79E 00	-6.80E 00	-1.65E 03	-5.81E 03	-5.84E 03
2.09E-01	7.83E 09	7.375E-04	7.378E-04	-7.437E-06	-7.481E-06	-9.479E-01	2.79E-01	2.42E 02	-6.06E 00	-6.12E 00	-1.44E 03	-6.17E 03	-6.22E 03
2.30E-01	7.20E 09	6.574E-04	6.577E-04	-7.338E-06	-7.382E-06	-8.649E-01	2.60E-01	2.62E 02	-5.40E 00	-5.51E 00	-1.29E 03	-6.62E 03	-6.64E 03
2.55E-01	6.62E 09	5.924E-04	5.926E-04	-7.237E-06	-7.281E-06	-7.874E-01	2.40E-01	2.83E 02	-4.79E 00	-4.96E 00	-1.16E 03	-7.10E 03	-7.11E 03
2.81E-01	6.03E 09	5.123E-04	5.125E-04	-7.135E-06	-7.179E-06	-7.152E-01	2.20E-01	3.05E 02	-4.23E 00	-4.46E 00	-1.04E 03	-7.64E 03	-7.64E 03
3.10E-01	5.54E 09	4.472E-04	4.473E-04	-7.033E-06	-7.077E-06	-6.495E-01	2.00E-01	3.24E 02	-3.73E 00	-4.00E 00	-9.35E 02	-8.25E 03	-8.24E 03
3.42E-01	5.02E 09	3.867E-04	3.869E-04	-6.931E-06	-6.975E-06	-5.897E-01	1.80E-01	3.51E 02	-3.28E 00	-3.59E 00	-8.39E 02	-8.97E 03	-8.96E 03
3.78E-01	4.52E 09	3.309E-04	3.310E-04	-6.831E-06	-6.876E-06	-5.355E-01	1.60E-01	3.73E 02	-2.86E 00	-3.21E 00	-7.51E 02	-9.71E 03	-9.79E 03
4.17E-01	4.03E 09	2.795E-04	2.795E-04	-6.733E-06	-6.777E-06	-4.875E-01	1.40E-01	3.94E 02	-2.51E 00	-2.90E 00	-6.77E 02	-1.04E 04	-1.04E 04
4.59E-01	3.56E 09	2.322E-04	2.323E-04	-6.639E-06	-6.683E-06	-4.440E-01	1.21E-01	4.13E 02	-2.20E 00	-2.63E 00	-6.15E 02	-1.21E 04	-1.21E 04
5.06E-01	3.10E 09	1.893E-04	1.894E-04	-6.551E-06	-6.596E-06	-4.026E-01	1.01E-01	4.24E 02	-1.92E 00	-2.38E 00	-5.57E 02	-1.30E 04	-1.36E 04
5.58E-01	2.67E 09	1.506E-04	1.506E-04	-6.472E-06	-6.516E-06	-3.618E-01	8.08E-02	4.23E 02	-1.64E 00	-2.15E 00	-5.03E 02	-1.50E 04	-1.56E 04
6.15E-01	2.24E 09	1.160E-04	1.160E-04	-6.401E-06	-6.445E-06	-3.209E-01	6.13E-02	4.13E 02	-1.38E 00	-1.95E 00	-4.58E 02	-1.82E 04	-1.82E 04
6.78E-01	1.82E 09	8.531E-05	8.534E-05	-6.340E-06	-6.384E-06	-2.769E-01	4.25E-02	3.89E 02	-1.12E 00	-1.82E 00	-4.24E 02	-2.22E 04	-2.22E 04
7.48E-01	1.40E 09	5.843E-05	5.845E-05	-6.292E-06	-6.337E-06	-2.230E-01	2.57E-02	3.42E 02	-8.33E-01	-1.73E 00	-4.04E 02	-2.85E 04	-2.65E 04
8.24E-01	9.65E 08	3.527E-05	3.530E-05	-6.260E-06	-6.304E-06	-1.505E-01	1.08E-02	2.69E 02	-5.12E-01	-1.77E 00	-4.14E 02	-4.09E 04	-4.08E 04
9.08E-01	5.19E 08	1.575E-05	1.578E-05	-6.245E-06	-6.289E-06	-5.943E-02	2.03E-03	1.17E 02	-1.81E-01	-2.26E 00	-5.26E 02	-7.67E 04	-7.65E 04
1.00E 00	0.00E-39	0.000E-39	0.000E-39	-6.243E-06	-6.288E-06	0.000E-39	0.00E-39	-1.32E 02	0.00E-39	1.00E 38	1.00E 38	1.00E 38	1.00E 38